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ANCIENT CALENDRICAL OBSERVING SITES IN CALIFORNIA'S MOJAVE DESERT AND SIERRA NEVADA

PART ONE

Calendrical Observations in the Providence Mountains

PART TWO

Ancient Indian Astronomers on the Middle Fork of the American River

Merle F. Walker

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Second edition, April 2013

Merle F. Walker

In memory of my friend,
fellow student, and colleague,
Gibson Reaves

PREFACE

The two reports contained in this volume constitute a record of the writer's studies from 1988–2008 of petroglyphs, pictographs and features at sites that appear to have been used by the Indians for astronomical observations. These sites are located:

(1) In the Providence Mountains in the Mojave Desert of southern California, discussed in Part One of this volume.

(2) On the Middle Fork of the American River in the Sierra Nevada of north-central California, discussed in Part Two.

The identification and study of sites used by the Indians for astronomical observations is of importance for two reasons. First, if we can identify the astronomical phenomena or events that were being observed, we may gain some insight into the astronomical knowledge of the users of the sites, and into their astronomically related ceremonies and practices. In some instances, we may also be able to establish the time periods in which the observations were made. Secondly, by studying the petroglyphs and/or pictographs associated with these sites, we may gain a greater understanding of the meanings of these symbols.

Studies of the petroglyphs and pictographs created by the Indians of the North American Continent began in the 18th and 19th centuries. These investigations were carried out by workers who had direct contact with Indians who still retained some knowledge of the meanings of these symbols, and still occasionally produced contemporary examples (Mallery 1893, and references therein; Martineau 1973, and references therein). It was the consensus of these workers that these symbols are not merely "art", but are, in fact, a form of pictographic or ideographic writing, designed to convey a specific message to the proficient reader. During the 20th century, this concept was further developed by LaVan Martineau (1973), who used the techniques of cryptanalysis to demonstrate that the petroglyphs are not simply artistic designs, but are indeed the symbols of a written language. Unfortunately, there are as yet only a few "Rosetta Stones" for this language, so that to date it has only been possible to translate a relatively small number of these symbols (Martineau 1973).

The study of petroglyphs and pictographs at observing sites is thus of considerable importance. If, as noted above, we can identify the astronomical event or phenomenon that was being observed, we may then be able to deduce what the authors of the associated inscriptions were writing about. This, in turn, may then help both to confirm the translations that have been made of previously studied symbols, and to determine the meanings of additional ones.

Therefore, in the reports presented here some use has been made of Martineau's (1973) findings on the structure and concepts of the pictographic language, and of some of the translations which he was able to make of particular symbols.

Martineau's work was based mainly on his studies of petroglyphs and pictographs in the Great Basin region. His findings are of particular relevance to the studies reported here since in both cases it is believed that the creators and users of the sites were peoples who shared a common ancestry with those of the Great Basin (Kroeber 1925:574–580; Gortner 1986:6–26). Thus, it is reasonable to expect that at least some of the symbols and language concepts used at the Middle Fork and Providence Mountains sites will be similar to those discussed by Martineau.

It should be noted, however, that the major conclusions of these two reports will remain essentially the same even if all reference to Martineau's work is excluded.

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1973 *The Rocks Begin to Speak.* K.C. Publications: Las Vegas.

PART ONE

Calendrical Observations in the Providence Mountains

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Acknowledgements

It is a pleasure to thank Prof. Eli Silver for his identification of the mineral corrensite, Dr. Arnold Klemola for calculating solar declinations from the JPL Ephemeris Program, and Richard Johns, Superior Color Lab, for preparing a number of the photographic illustrations. I am particularly indebted to the late Prof. Gibson Reaves for providing the obliquity and season-length data in Appendix 2, as well as for a number of very helpful discussions. Finally, it is a great pleasure to thank Dr. Robert H. Gargett for his invaluable research and editorial assistance in preparing the final manuscript of this paper for publication.

1

Introduction

Two sites in the Providence Mountains, located in the Mojave Desert of southern California, and their use for calendrical observations of the sun, have been described by Rafter (1985, 1987, 1991). These sites, CA–SBR–291 and CA–SBR–535, referred to by Rafter as Counsel Rocks and Shelter Rock, respectively, possess sunrise or sunset alignments as well as pictographs, petroglyphs and light-and-shadow events that indicate that they were used to determine the dates of the solstices, the equinoxes, and a mid-spring/summer event. The present paper discusses the results of further studies by the writer that provide support for Rafter's interpretations, and which bring out additional details concerning the observations that were made at these two sites and at a third location nearby.

2

Summer Solstice at Shelter Rock

Rafter (1987) notes that at the summer solstice, the upper limb of the rising sun, as observed from Shelter Rock, first appears in the bottom of a V-shaped notch on the eastern horizon. The emergence of the solar limb, precisely in the bottom of the "V," is a dramatic and spectacular sight. It was likely even more so during the ancient occupation of the site. As late as the 1980s, the first rays of the sun sometimes exhibited the "green flash," due to atmospheric refraction, and on one occasion in 1988 a deep, vivid *blue* flash was observed. These appearances require air with low aerosol or dust content. Such conditions were probably fairly common in prehistoric times, but are much less so today, owing to the increasing atmospheric pollution in the region. No green or blue flashes have been observed in recent years.

As discussed by Rafter (1987), the presence of a number of sun-like pictographs, executed in red or reddish brown and sometimes white pigment on the ceiling and rear wall of the Shelter Rock overhang, attests to the use of this site for observations of the sun. That the *summer solstice* sunrise was at least one of the events being observed is suggested in particular by two of these sun symbols, shown in Figures 1 and 2, whose locations, and in one case shape, indicate that they almost certainly refer to the sun at the solstice.

Note that, owing to the faded condition[1] of the Shelter Rock pictographs, illustrations of them reproduced in this paper were prepared in the following manner: color photographs of the symbols were first digitally processed to enhance the color of the remaining red pigment. Using these false-color images as a guide, the natural black-colored markings on the rock surface were then slightly suppressed. Lastly, black and white prints were made from these processed images. On these prints, the painted areas stand out more clearly from the natural markings than on direct black and white photographs of the pictographs (note that several of the enhanced or false-color images used in this process are reproduced in Appendix 1).

The overhang at Shelter Rock measures about 9 m in width and has a depth at floor level of 3.0 m, decreasing to 1.5 m at the north end. At the south end, about 1.5 m of the floor's width is blocked by a boulder 0.9 m high, 1.8 m long and 1.5 m wide which was at one time a part of the ceiling and rear wall of the overhang. The solstice sunrise notch is only visible from the north and south ends of the overhang. In the middle, the view is blocked by a large foreground rock located about 23 m in front of the rear wall of the shelter.

Standing in a crouched position in the proper location, the solstice V can be framed within a notch in the north side of the foreground rock. Directly behind this point, on the rear wall of the overhang and at the eye-level for viewing this alignment (117.5 cm above the shelter floor), is the first sun symbol, shown in Figure 1. Seated on the floor of the overhang, the observer must move slightly to the north of the position of the rear wall sun symbol in order to see the solstice notch, owing to the greater northward extent of the foreground rock towards its base. Directly above the point where the seated observer, with his eye about 70 cm above floor level, can first see the solstice V is the second sun symbol, shown in Figure 2. These symbols were first recorded by Rafter (1987) and are shown in his Figures 3e and 6 (rear wall symbol), and 11 (ceiling symbol). Figures 1 and 2 demonstrate that both of the sun symbols are elliptical in outline when viewed perpendicularly to the rock surface, whereas normally such symbols are circular. It should be noted that a perfectly circular pictograph or petroglyph was one of the easiest figures to construct: all that was required was a forked stick of the proper dimensions. The ends of the fork would be charred in the fire, and the stick then used as a compass to draw a perfectly circular charcoal guide line. Thus, deformed circles are most likely not the result of poor workmanship, but were intended to have their particular shape for some specific reason. The major axis of the rear-wall symbol is vertical, while that of the ceiling symbol points to the solstice sunrise notch. This latter symbol was surmised by Rafter (1987) to represent a comet. However, both its location and orientation indicate that this symbol, like that on the rear wall, refers to the sun at the solstice.

An ellipse, having major and minor axes a and b, respectively, will appear circular when viewed in the direction of its major axis at an angle, i, above the plane of the ellipse such that $\sin i = {}^{b}\!/_{a}$. In the case of the rear-wall symbol, the ratio of the axes of the ellipse is ${}^{b}\!/_{a} = 0.80 \pm 0.03$, corresponding to $i = 54° \pm 3°$. (The errors quoted here and throughout this paper are the standard deviations.) An indication of ellipticity is also to be seen in the rays of the sun symbol. These features are rather irregular, in part due to weathering of the pictograph. However, measuring only the lengths of the rays nearest the major and minor axes on each side of the ellipse, we find ${}^{b}\!/_{a} = 0.84 \pm 0.04$ or $i = 57° \pm 4°$. The rear wall of the shelter, at the point where the sun symbol is located, is inclined at an angle of $h = 36.^{\circ}3 \pm 0.^{\circ}4$ above the horizontal. Thus, for an observer located directly below the sun symbol, $i \simeq 54°$, while for an observer looking horizontally at the symbol $i \simeq 36°$. Photographs of the pictograph taken from these two positions are reproduced in Figure 3.

The upper photograph was taken from a point directly below the symbol, while the lower shows the pictograph viewed horizontally. In the upper photograph,

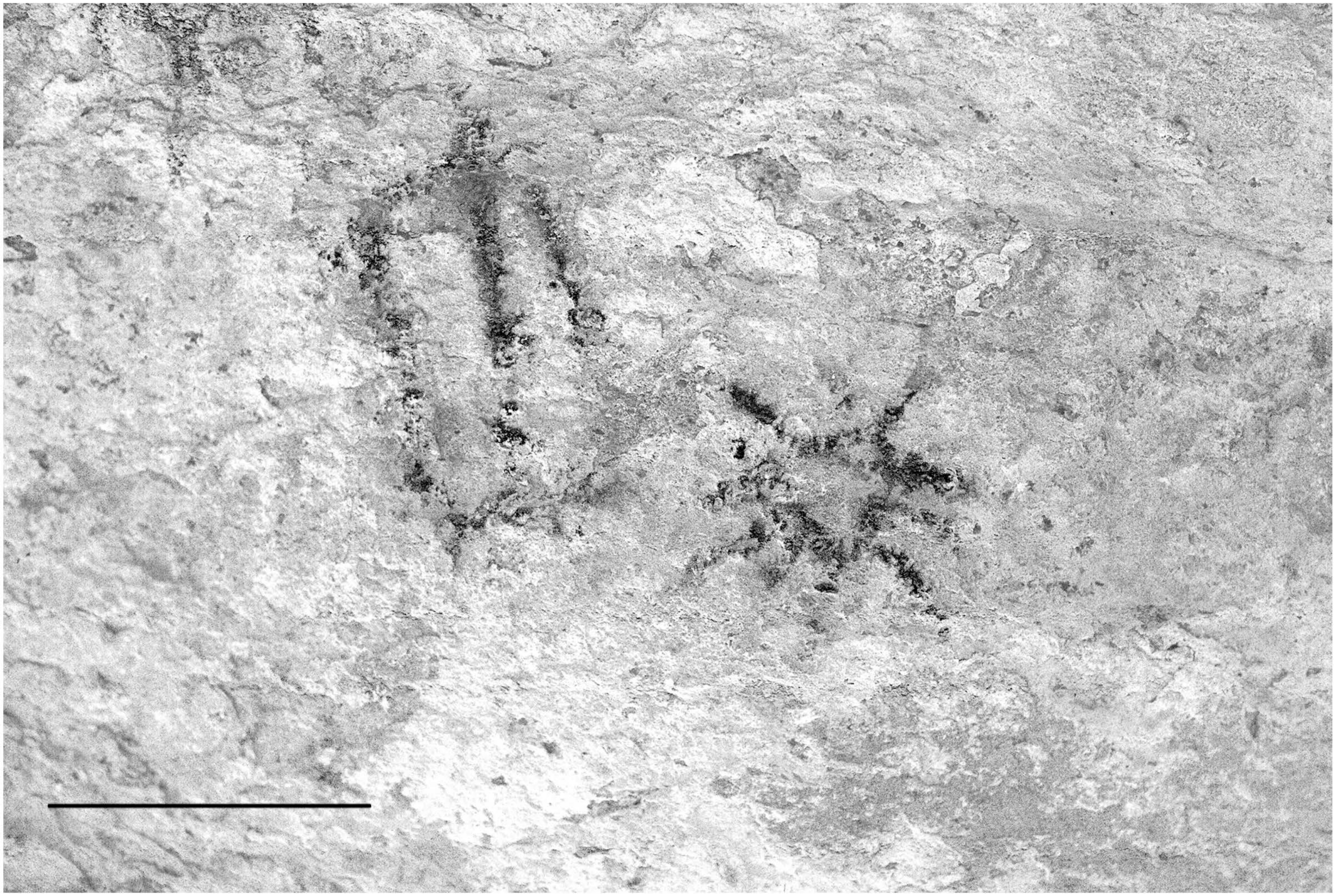

Figure 1. Sun symbol. Pictograph on rear wall of Shelter Rock overhang. Top of symbol uppermost in the figure. Photograph taken perpendicular to the rock surface. See text. Scale bar = 10 cm.

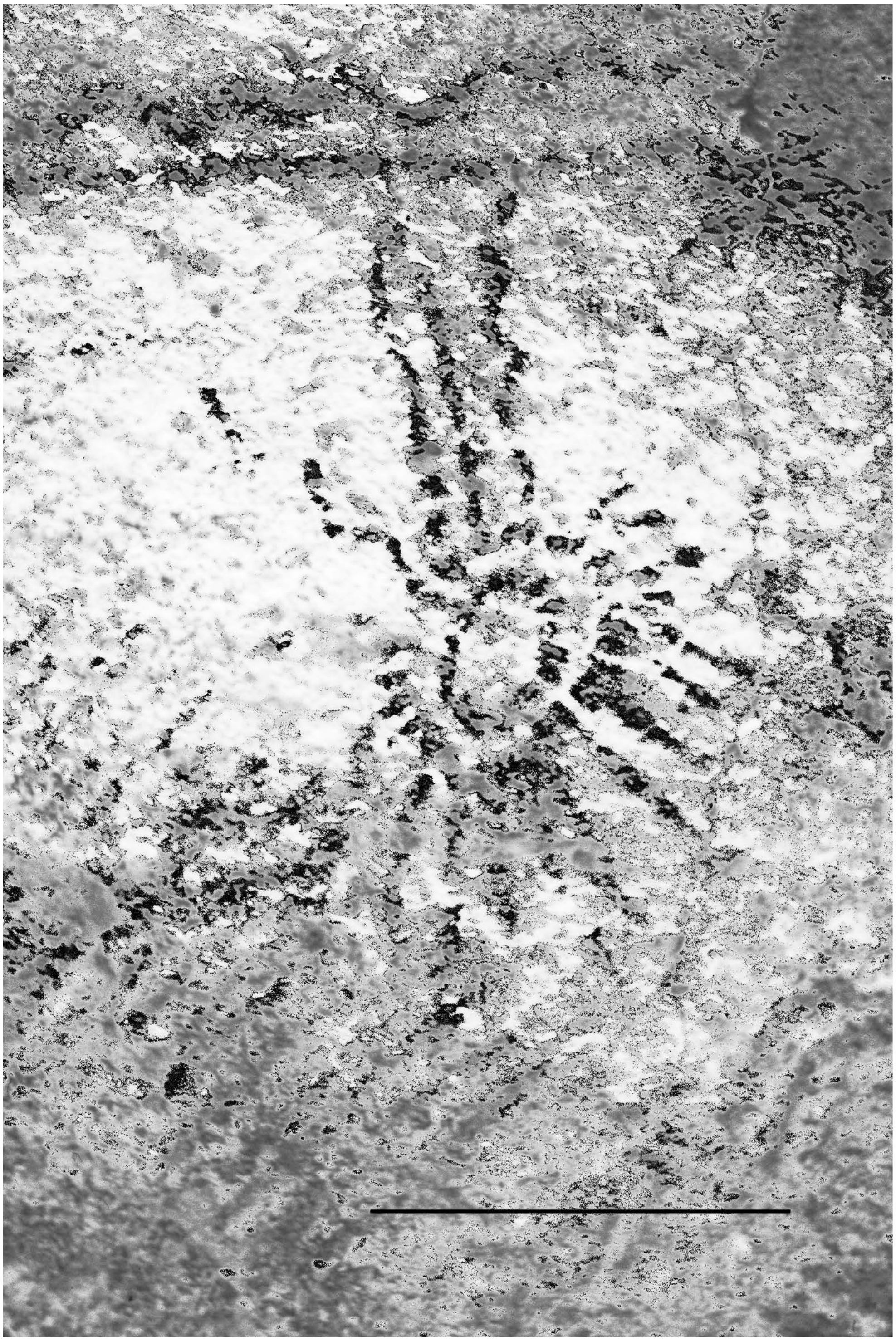

Figure 2. Sun symbol. Pictograph on ceiling of Shelter Rock overhang. West at the top and south to the right of the figure. Photograph taken perpendicular to the rock surface. See text. Scale bar = 20 cm.

Figure 3. Rear wall sun symbol shown in Figure 1. Top: Viewed from a point directly below the pictograph. Bottom: Viewed horizontally. See text.

the outline of the pictograph is nearly circular, while in the lower, it is again elliptical, with its major axis now horizontal instead of vertical. It would appear, therefore, that the pictograph was painted by an observer sitting on the floor beneath the symbol and reaching up to paint it so that it appeared circular to him as he viewed it from that position.

As indicated above, the major axis of the ceiling sun symbol in Figure 2 points to the solstice sunrise notch on the horizon. Here, the ellipticity of the symbol was determined from measures made along the major and minor axes at the midpoints and edges of the white and the inner red ellipses. The average of five sets of these measures gives $i = 42\overset{\circ}{.}7 \pm 1\overset{\circ}{.}0$. In the direction of the major axis, the ceiling of the shelter at the location of the pictograph slopes upward towards the northeast at an angle of about $h = 2°$. Thus, the angle of the line of sight along which the pictograph will appear circular is $h \simeq 45° \pm 1°$ above the horizontal. The pictograph is located at a height of 146.5 cm above the floor of the shelter, or (probably) a few centimeters less than the height of the painter. There appears to be a natural tendency to have the line of sight at $h \simeq 45°$ when drawing a design on such a ceiling, and it would appear that the painter of the sun symbol worked in this position, aligning his line of sight along the line from the pictograph to the solstice notch and painting the symbol so that it then appeared circular to him. In addition, as seen from below by an eastward-facing observer, if the pictograph represents the rising sun, then the "upward" direction is to the west of the symbol. Thus, the long westward-extending rays emanating from the symbol may represent the initial burst of light from the sun when it first emerges in the bottom of the V, confined to the upward direction by the sides of the notch.

According to Martineau (1973:50), wavy lines represent an incomplete or ongoing motion. Therefore, undulations of the westward-extending rays may indicate ongoing (upward) motion of these rays and, by extension, of the sun, *i.e.*, that the sun is rising (in the notch). Also, Figure 2 shows that unlike the usual sun symbol which consists of a circle with external, radial rays, the ceiling symbol consists of two concentric ellipses—or circles as seen by the painter. A series of concentric circles means "many holding in one place" (Martineau 1973:100–101). Thus, a single interior circle might have been added to the basic sun symbol to express the idea of "few holding," meaning that the sun rose in the same place (in the notch) for only a short time. This interpretation is not entirely certain, since two concentric circles can also mean "nothing there" or "empty" (Martineau 1973:38). However, given the context of the symbol, few holding is more likely to apply.

A third symbol that may be related to the summer solstice is illustrated in Figure 4. This pictograph was described by Rafter (1987) as a sun-like symbol and is shown in his Figure 3d. Painted in red pigment, the pictograph consists of two somewhat deformed concentric circles, having maximum and minimum diameters of 7 and 5 cm (inner circle) and 11 and 9 cm (outer circle), and lacks

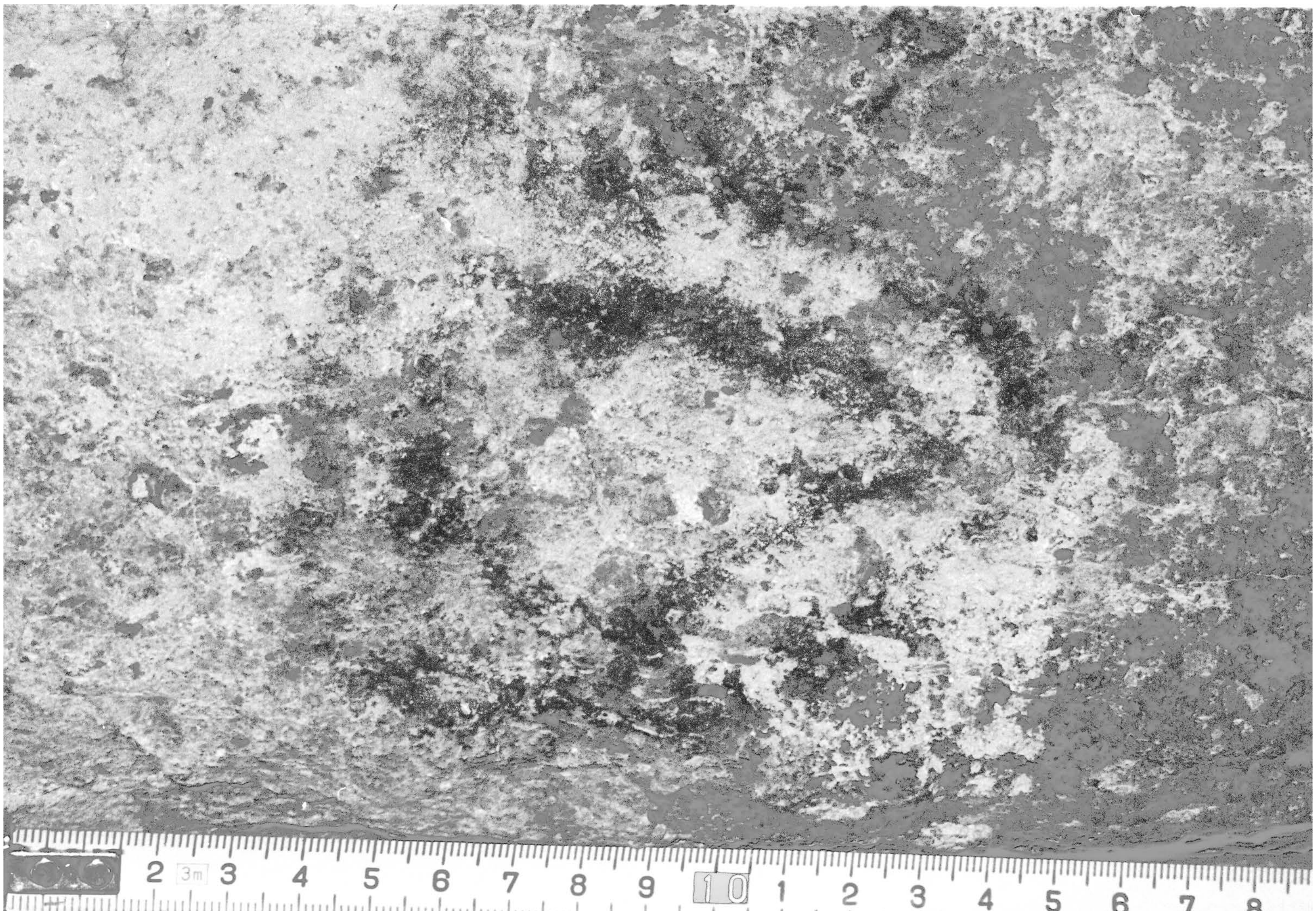

Figure 4. Possible sun symbol on rear wall of Shelter Rock overhang, photographed perpendicular to rock surface, top uppermost. See text. Scale here and in other figures is in cm.

the exterior rays characteristic of sun symbols. Thus, its identification as a sun symbol is somewhat uncertain. The symbol is located some 15 cm to the right and roughly 24 cm below the rear wall sun symbol shown in Figure 1, at a height of about 84 cm above the shelter floor. That it might be related to the solstice sunrise observations is suggested by the fact that with the observer's eye at the position of the center of the pictograph, the solstice V is seen just at the left-hand end of the bottom edge of the notch in the north side of the foreground rock, at the point where the northern profile of the rock resumes its downward plunge. Seated within the shelter, the observer's eye would probably have been about 60–70 cm above the floor level, so that to the left (south) of the symbol, the horizon V would have been invisible.

Rather than a sun symbol, the pictograph might indicate few holding and refer to the sun rising in the V as with the ceiling symbol in Figure 2. Or, it might be a modified nothing there symbol which, as discussed above, normally consists of two concentric circles (Martineau 1973:38). Figure 4 shows that the left-hand half of the symbol does in fact consist of the halves of two concentric circles. However, in the right-hand half, the two curves, instead of being half circles, are drawn out to a point. As discussed above, perfect circles were easy to construct. Thus, deformed circles are likely to have their particular shape for some special reason. In the present instance, the tear-drop shape of the symbol may have been created in order to convey the message that the nothing there-ness (*i.e.*, the invisibility of the horizon V) decreases or ends as the observer moves to the north of the symbol. Or, in other words, that an observer kneeling or sitting on the floor of the shelter must locate himself north of the symbol in order to view the summer-solstice sunrise.

At the south end of the shelter, the solstice notch is again just visible on the south side of the foreground rock from a recess in the rear wall of the overhang, behind the large rock discussed earlier. This recess has a width of 50 cm and a space of 40 cm between the rear wall and the western side of the rock, providing just enough space for an observer to stand within the recess and view the solstice V over the top of the shelter-floor boulder. Whether observations of the solstice sunrise were made from this point is uncertain. On the ceiling, directly above the boulder and 80 cm above its top, is an oval-shaped pictograph 16 cm wide (east–west) and 21 cm long (north–south), painted in red pigment. This pictograph is rather faint and indistinct, and its exact form and meaning are unclear. It does not, however, appear to be a typical sun symbol.

The geometry of the solstice notch sunrise is shown in Figure 5. This figure was prepared from a photograph of the northeastern horizon, taken from a point directly above the observing position within the overhang. The scale of the figure was determined by measuring the distances between key points on the original photograph and converting these to angular units using the scale-factor for the camera lens derived from measurements of star positions on photographs taken with that lens.

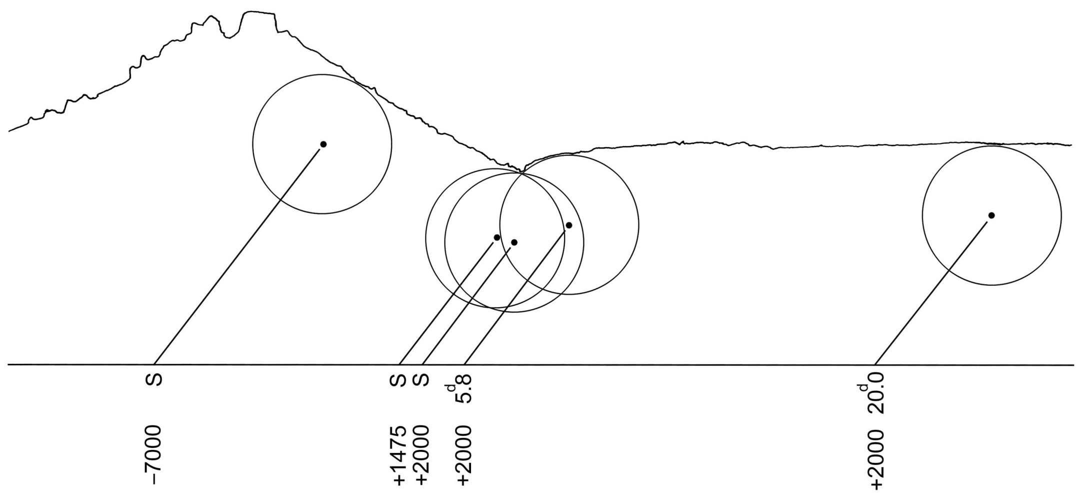

Figure 5. Geometry of the summer solstice sunrise at the Shelter Rock overhang. Northeast skyline traced from a photograph taken directly above the observer's position within the overhang. The horizontal line is an arbitrary level line. Circles represent the disk of the sun, 32′ in diameter, when the upper limb appears above the skyline on the indicated dates. The inclined lines indicate the diurnal path of the center of the solar disk. The figure shows the solstice sunrise positions (S) in 7,000 B.C., A.D. 1475 and A.D. 2000, plus the sunrise points $5^{\mathrm{d}}\!.8$ and $20^{\mathrm{d}}\!.0$ before and after the A.D. 2000 solstice.

The V shape of the solstice notch is produced by the overlapping profiles of two ranges of hills at slightly different distances. Thus, the precise shape of the notch varies fairly rapidly with lateral changes in the location of the observer. As seen from the north end of the Shelter Rock overhang, the V narrows down to a square-shaped aperture at its bottom. This feature has a width and a depth of about two arc minutes, and thus forms a very precise foresight.

The circles in Figure 5 represent the disk of the sun, 32′ in diameter, at the moment when its upper limb first appears above the skyline on the indicated dates. This figure predicts, and observation confirms, that as the sun approaches the solstice, the sunrise point moves slowly and uniformly northward along the horizon until five days before the day of the solstice. On this fifth day, the sunrise point is still well south of the solstice notch (by about nine minutes of arc). But on the following day (the fourth day before the day of the solstice), it has "jumped" over into the solstice notch. The sun then continues to rise in the notch for a total of ten days. The sun never rises to the north of the notch even though it continues to move northward along the skyline until the date of the solstice, its azimuth (A) decreasing by $\Delta\ A \simeq -06\overset{\prime}{.}4$. When it first appears in the notch, the sun rises at about $4^{\mathrm{h}}\ 40^{\mathrm{m}}$ PST; when it leaves, sunrise is at about $4^{\mathrm{h}}\ 42^{\mathrm{m}}$ PST.

The ancient observers were thus provided with a means of determining and predicting the date of the summer solstice which was not only spectacular, but was also highly accurate and required observations over only a relatively small

Figure 6. Thirteen-line symbol on rear wall of Shelter Rock overhang. Top of symbol uppermost in the figure. See text. Scale bar = 20 cm.

Figure 7. Smaller multi-line symbol on rear wall of Shelter Rock overhang. Top of symbol uppermost in the figure. See text. Scale bar = 20 cm.

number of days. Generally, the date of the solstice would have been determined by observing the alignment of the sunrise point with some suitable feature on the horizon before and after the solstice and dividing the interval in half. Near the solstice, the motion of the sunrise point along the horizon is nearly undetectable for a period of about a week. Thus, to determine the solstice date with an error of one day or less, this alignment would have had to be observed while the daily azimuthal motion of the sunrise point was still fairly large. At Shelter Rock, this motion amounts to only $\Delta\ A \simeq 8'$/day two weeks and $16'$/day one month before or after the solstice. Thus, without the solstice notch, observations over a relatively long period of time would have been required.

Sunrise observations have now been obtained with the sunrise point out of the notch when the declination of the sun at sunrise was $\delta_{\odot} \leqslant +23^{\circ}\,21'.09$, and with the sunrise point in the notch when $\delta_{\odot} \geqslant +23^{\circ}\,21'.51$. We shall therefore assume in the discussion which follows that the sun rises in the notch when its declination at sunrise is $\delta_{\odot} \geqslant \delta_{c} = +23^{\circ}\,21'.3$, where δ_{c} is the critical value of $\delta_{\odot}$ for the sun to first appear in the notch, and is the average of the two preceding values.

In A.D. 2000, $\delta_{\odot} \geqslant \delta_{c}$ for $9^{d}.8$. However, the obliquity of the ecliptic, ϵ, and hence the number of days, N, when $\delta_{\odot} \geqslant \delta_{c}$, varies with time, owing to the perturbing effects of the moon and planets on the earth's orbit. The secular variation of ϵ with time is discussed in and tabulated in Appendix 2. In addition, the daily motion of the sun in declination varies with time due to the elliptical shape of the earth's orbit and to the fact that both the ellipticity and the spatial orientation (the longitude of perihelion) of that orbit change with time. Superimposed on these long-term variations is an 18.6-year oscillation or nutation in the value of ϵ due primarily to the lunar perturbations. This nutational variation has, at present, a range of $\Delta\ \epsilon = 18''$, and produces a total change in N of $0^{d}.30$.

The variation of N with time is given in Table 1. For the interval from 8,000–4,000 B.C., the values of N were calculated from the values of ϵ listed in Appendix 2. For the interval from 3,000 B.C.–A.D. 2650, the values of N were calculated using solar declinations derived from the JPL Ephemeris Program (Giorgini et al. 1966). In Table 1, the values of N from 8,000–4,000 B.C. are given only to the nearest $0^{d}.5$; for 3,000 B.C.–A.D. 2650, they are given to $0^{d}.1$. From Appendix 2 and Table 1, we see that the obliquity had its maximum value in about 7,500 B.C., at which time, $N = 31^{d}$, so that the summer solstice occurred on the 16th day that the sun rose in or north of the solstice notch. At this time, the solstice sunrise point was located far to the north of the notch, as shown in Figure 5.

As Figure 5 demonstrates, the solstice sunrise point continued to lie north of the notch until about A.D. 1450. At that time, the sunrise event clearly became much more impressive, and very likely acquired increased ceremonial significance. As can be seen from Table 1, the number of days that the sun rose in the notch was then $N = 13.4$, and the summer solstice occurred on the seventh day that the sun rose in the notch.

On the rear wall of the Shelter Rock overhang are two pictographs, each con-

Table 1. Number of Days Sun Rises In or North of the Summer Solstice Notch

Epoch[a] Year	Days N
−8,000	31
7,000	31
6,000	30.5
5,000	30
4,000	29
3,000	26.9
2,000	25.2
1,500	24.0
1,000	22.7
− 500	21.3
+ 01	19.7
500	17.9
1000	15.7
1500	13.1
2000	9.8
2500	4.1
2600	2.8
+ 2650	0.0

[a]B.C. epochs negative; A.D. epochs positive.

sisting of a horizontal line with vertical lines extending downwards from it. Photographs of these symbols are reproduced in Figures 6 and 7. The larger symbol, shown in Figures 6 and 11, is located with its south end about 120 cm north of the sun symbol in Figures 1 and 3, and with its top 118 cm above the shelter floor. This pictograph has 13 vertical lines that are approximately 7 cm long. It measures 33 cm between the outer edges of the vertical lines. The pictograph was painted using reddish pigment, and is considerably faded since its location does not completely protect it from the effects of the weather. The smaller symbol, also painted with red pigment, is shown in Figure 7. This pictograph is located with its south end about 190 cm south of the south end of the symbol in Figure 6, with its top about 63 cm above the shelter floor. The number of vertical lines in this pictograph is uncertain. Being lower down on the rear wall, it is more exposed to the weather, and is therefore considerably more faded than the larger 13-line symbol. At present, only three of the vertical lines, which have lengths of about 5 cm, are clearly shown on the enhanced-color prints. In 1934 (according to the date scratched into the adjacent rock surface), someone believed he could, at that time, detect a total of nine lines, which he indicated by overlying them with scratch marks. Three of these scratched lines do agree with the positions of the still-visible painted lines. However, at least some of the other scratches appear to mark natural black stains on the rock, and most of them have a closer spacing than that of the remaining painted lines. Thus, the scratched lines from 1934 probably do not correctly indicate the original number of painted lines.

One possible interpretation of this type of pictograph is that they are "count" symbols. If so, then the 13-line symbol in Figure 6 may have been constructed to record the number of days that the sun rose in the solstice notch. This interpretation is supported by Rafter's (1993) study of a similar pictograph at a site (SBCM 1524-E) in Cactus Valley, California. Rafter's work indicates that this pictograph is a set of count lines showing the number of days near the time of the summer solstice when the sun appeared to rise at the same point on the horizon.

Two other sets of possible count lines in the shelter are illustrated in Figures 8, 9, 11–13. Like the symbols discussed previously, these are also painted with red pigment. The first of these pictographs, shown in Figures 8 and 9, is located just above the top of the rear wall of the shelter, 140 cm above the shelter floor and about 40 cm out from the vertical portion of the rear wall. It is about 75 cm south of the rear-wall sun symbol in Figures 1 and 3. This symbol consists of a top bar, 14 cm long, with seven descending (as one faces the rear wall) lines that are approximately 9 cm in length. The symbol has a somewhat smudged, red-painted, 16-rayed, double-circle sun symbol just below it, suggesting that the set of lines does relate in some way to the sun. These two pictographs were first recorded by Rafter (1987), and are shown in his Figure 8. If the set of seven lines is a count symbol, it may then indicate the number of days that the sun rose in the notch, up to and including the day of the solstice. Connection to the sun is further suggested by the presence of another red-painted possible sun symbol,

Figure 8. Sun and sun-like symbols plus seven-line symbol on ceiling of Shelter Rock overhang. East at top, north at right of figure. See text. Scale bar = 40 cm.

Figure 9. Detailed view of ceiling seven-line and sun symbols shown in Figure 8. Northeast at top, northwest at right of figure. See text. Scale bar = 10 cm.

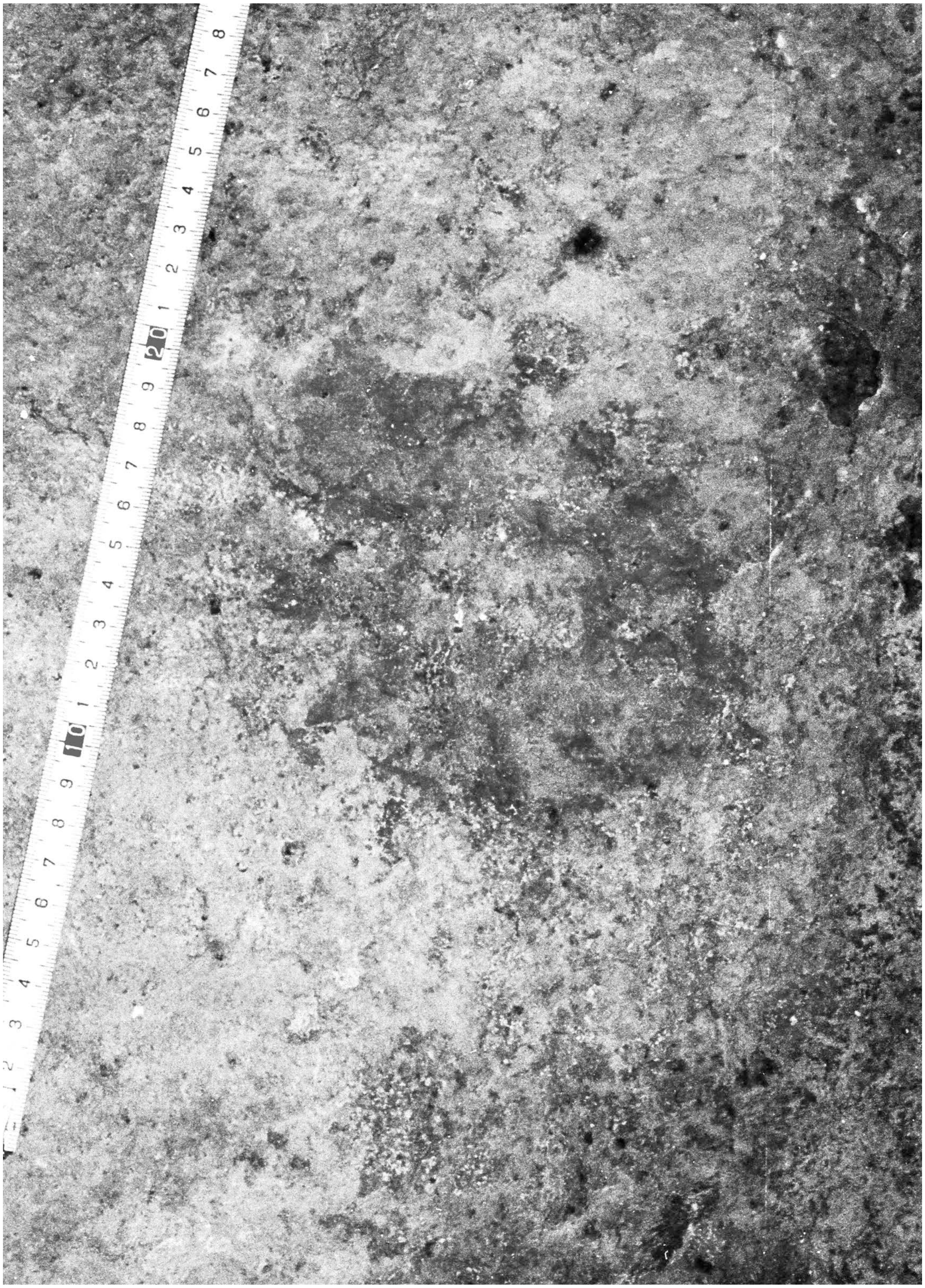

Figure 10. Detailed view of ceiling sun-like symbol shown in Figure 8. West at top, north to left in the figure. See text.

shown in Figures 8 and 10, located on the ceiling of the shelter some 60 cm out from the seven-line symbol, and 136 cm above the floor. This symbol consists of two concentric circles, and has 12 rays extending from the inner circle out to just beyond the outer one; the diameter of the outer circle is approximately 10 cm. The concentric circles of these two sun symbols may, like the concentric ellipses of the ceiling sun symbol in Figure 2, have been intended to denote the solstice sun, staying in one place for only a short time.

The second set of lines is illustrated in Figures 11–13. Figures 11 and 12 show the rear wall of the shelter northward from the 13-line pictograph, which is seen at the left in Figure 11. This set consists of seven lines, running approximately north and south, but lacks the top connecting line present in the other three sets. It is located 116 cm above the shelter floor, with its south end 30 cm north of the north end of the 13-line symbol. The set of lines measures about 23 cm between the outer edges of the end lines. Six of these lines are approximately 8 cm long, while the seventh (at the left-hand or south, end of the set) is about 4 cm long. Relationship of these lines to the sun is suggested by the presence of what appears to be a smudged sun symbol, consisting of an open circle about 6 cm in diameter, with an indeterminate number of rays extending 0.5–1.0 cm beyond the circle. This pictograph is located about 10 cm from the right-hand (or upper) end of the first (northernmost) line of the set, and is positioned so that it is bisected by the extension of a straight line drawn through the length of that first line. A second pictograph, consisting of a smudge of red paint, is located at the left-hand end of the set, about 5 cm from the right-hand end of the last (southernmost) line of the set, and is positioned so that its right-hand edge is tangent to the extension of a straight line drawn through the length of that last line. This marking is somewhat irregular in shape, due apparently to the flaking off of bits of the painted rock surface, but appears to have originally been a filled circle about 3 cm in diameter. According to Martineau (1973: 48-50, 52, 54, 56, 57, 66), an open symbol indicates "good" or "light," while a filled symbol indicates "difficulty" or "darkness." In addition, a large symbol indicates something "close by" or "coming closer," and a small symbol indicates something "distant" or "going away." Thus, the larger, open sun symbol could indicate the sun getting closer and brighter, *i.e.*, moving northwards and giving longer and brighter/hotter days. The smaller filled circle could then indicate the sun going away and becoming darker, *i.e.*, moving southward with the days becoming shorter and darker/cooler. If, now, the seven lines are day-count lines for the rising of the sun in the solstice notch, then the location of the right-hand open sun symbol might indicate that the sun—or sunrise point—was moving north on the first day of the count. Likewise, the position of the smaller filled circle—just beyond the last count line—could indicate that the sun begins to move southward *after* the date of the last count line. The set of lines could thus represent the number of days that the sun rose in the solstice notch up to the time of the solstice (*i.e.*, $6\overset{\mathrm{d}}{.}5$, $N = 12^{\mathrm{d}}$).

Figure 11. Rear wall of Shelter Rock overhang. Thirteen-line symbol, shown in Figure 6, at left, seven-line symbol at right. Top of wall and ceiling uppermost in figure. See text. Scale bar = 40 cm.

Figure 12. Rear wall and ceiling of Shelter Rock overhang. View to right (north) of section shown in Figure 11. View looking to the northwest. Top of wall and ceiling uppermost in figure. See text. Scale bar = 50 cm.

Another pictograph that may be related to the solstice sunrise phenomena is that illustrated in Figures 14 and 15. This pictograph, executed in red, and possibly white, pigment, is located on the ceiling of the overhang eastward of the ceiling sun symbol described above (see Figs. 2 and 15), and consists of (from south to north) an increasingly broad wedge of pigment 19 cm long, followed by seven separate short lines measuring 25 cm between the outer edges of the end lines. The azimuth of the axis of this symbol is $A = 8^\circ$ and, as can be seen in Figure 15, the ceiling sun symbol and its long westward-extending rays lie close to the perpendicular to this axis from the northernmost of the seven lines. This positioning suggests that the two symbols are related and thus that the linear pictograph, like the sun symbol, refers to the solstice sunrise events. The linear pictograph may have been intended to represent the motion of the sunrise point near the solstice. The continuous strip of pigment depicts the gradual northward movement of the sunrise point from day to day along the horizon. As indicated above, symbols increasing in size indicate something coming closer (Martineau 1973: 52, 54, 56, 57). Viewed in this way, the wedge shape of this portion of the pictograph could be showing us that the sun is approaching the solstice point. Then, the sunrise point "jumps" into the notch and the day of the solstice is the seventh day that it rises in the V, as enumerated by the seven counting lines.[2]

So, each year the sun rose in the notch and on the seventh day the solstice was celebrated. However, as time went on, the total number of days that the sun rose in the V continued to decrease, as detailed in Table 1. By around A.D. 1600 that number had decreased to $N = 12\overset{\mathrm{d}}{.}5$, and by about A.D. 1670 it had shrunk to $N = 12\overset{\mathrm{d}}{.}0$. That change appears to have been noted by the Shelter Rock observers and carefully and accurately recorded in the 7-line pictograph panel discussed above. But what was to be done about the date of the summer solstice celebration? By this time, the tradition that the solstice was to be celebrated on the seventh day that the sun rose in the solstice notch was, of course, firmly established. What were the observers to do? On the one hand, having to change the traditional rule for determining the date of the solstice was not a very happy prospect. Yet on the other, their observations clearly showed that the old rule was no longer correct. And, in any case, the correction to the date of the solstice was $0\overset{\mathrm{d}}{.}5$. How could they deal with that?

The observers' solution was ingenious. They constructed a model of the event that would satisfy the observations while at the same time allowing them to preserve the traditional rule for determining the date of the solstice. They illustrated their model with the pictograph shown in Figures 12 and 16. Rendered in reddish brown pigment on the ceiling at the north end of the shelter and 125 cm above the floor, this pictograph consists of four parallel lines, 25 cm in length, the two right-hand lines being narrow and the two left-hand lines wide, with count marks along the outer sides of the outermost lines. Along the right-hand side there are six of these count marks, and on the left-hand side, five. The azimuth of the four parallel lines is $A \simeq 320^\circ$, or roughly parallel to the length of the

Shelter Rock overhang. The total width across the four parallel lines is 21 cm. This pictograph is the northernmost of the ceiling pictographs in the overhang, with the exception of a single, short red line, visible in Figure 12. This line is 4 cm long and 10 mm wide, its south end beginning 14 cm north of the north end of the westernmost of the four parallel lines. The right-hand edge of the line aligns with the left-hand edge of the westernmost of the parallel lines. That alignment suggests some relationship between these symbols. Possibly, the line is a locator symbol (Martineau 1973:17, 18), directing the reader's attention to the pictograph just described, situated a "short distance ahead" (in this case, "above").

To the ancient observers, the solstices were the natural division points of the year, separating it into two distinct parts. In one, the sunrise (and sunset) point moved northward along the horizon, and the length of the day and the intensity of the sunlight increased. In the other, the sunrise (and sunset) point moved southward, and the length of the day and the intensity of the sunlight decreased. As discussed above, a broad or filled-in petroglyph or pictograph feature indicates "difficulty," "darkness," or "obscuration" (Martineau 1973:48–50, 66). Thus, the inner two of the four parallel lines could represent the solstice, dividing the year into two parts: One in which the world is becoming lighter, indicated by the narrow line, and the other in which it is becoming darker, indicated by the broad line. The two outer lines are the bars of two sets of counting symbols, turned so that they run northwest to southeast along the right- and left-hand sides of the pictograph. The right-hand count of six, associated with the narrow lines, refers to the time before the solstice, and the left-hand count of five, adjoining the broad lines, to the time after the solstice. The entire pictograph thus states that the sun now rises in the horizon notch for six days before the day of the solstice, but for only five days afterwards. With this model, the observations of N were correctly represented, and the tradition of celebrating the solstice on the seventh day that the sun rose in the notch was preserved.

Note that while the lines of the left-hand set of five all have essentially the same length, those of the right-hand set of six increase in length by a factor of nearly two, going from the southeast to the northwest ends of the set. The reason for this increase was probably to further affirm to the reader that these lines refer to the interval that the sun rises in the horizon V *before* the solstice. As discussed above, increasingly larger symbols indicate something coming closer (Martineau 1973: 52, 54, 56, 57). Thus, the increasing line lengths indicate that the sun is coming "closer," i.e., that the sun, or sunrise point, is moving northward.

The count, then, runs northwestward, along the northeast side of the pictograph, to the solstice. After the solstice, it then runs southeastward along the southwest side of the pictograph and, being shorter, ends before reaching the point opposite the first line on the right-hand side. Why do the left-hand count lines not decrease in length as they progress southeastwards? If the left-hand lines decreased in length, there would then be similar-looking sets on both sides of the pictograph, and the painter may have felt that this might be confusing to the reader; progressively increasing the lengths of the right-hand lines while making the left-hand set shorter ("more distant"), and of approximately the same length as the shortest of the right-hand lines, made it clearer which set referred to the pre-solstice interval.

That this pictograph was considered important is shown by the care that was taken in constructing certain parts of it. Measurements of an enlarged (0.80x scale) color print of Plate VIII reveal:

(1) While three of the four parallel lines appear to have been drawn freehand, being neither straight nor uniform in width along their lengths, the fourth—on the right-hand side of the set—is perfectly straight and uniform in width, suggesting that it was painted using a guide line, such as a cord stretched across the rock surface.

(2) The two sets of count lines are not perpendicular to the four parallel lines. This most likely results from the painter painting them as perpendicular from a viewing point at some compound angle to the perpendicular to the rock face; the lines can be made to appear perpendicular by viewing Plate VIII (or Figure 16) from a point beyond the top of the figure, along a line of sight making an angle of $h \sim 45°$above the plane of the figure and parallel to the four parallel lines, but offset sideways to align with the outer ends of the set of six count lines.

The practice of creating symbols to have their desired shapes when viewed from their painter's or engraver's position rather than on the face of the rock itself appears to have been a fairly common one. We have already seen examples of this procedure in the sun symbols at Shelter Rock, as described above. Additional examples at Counsel Rocks are discussed in Sections 3 and 5, below, and at site MFM in Part 2, Section 2 of this volume.

(3) The mean line length of the left-hand count lines is 61.5 ± 1.8 mm, with an average deviation from the mean of ± 2.8 mm. The mean distance from the outer edge of the nearest parallel line to the outer ends of the count lines is 68.8 mm ± 1.2 mm, and the average deviation from the mean is ± 2.0 mm. The mean spacing of the lines is 35.1 ± 3.5 mm, average deviation from the mean ± 4.8 mm.

(4) In the right-hand set six lines, the distances from the center of the adjoining (parallel set) straight line to the outer ends of the count lines, measured along the lengths of these lines, vary linearly with distance along the set, the average deviation from the regression line being ± 2.3 mm, suggesting that here, too,

a (possible stretched cord) guide line was used to locate these end points. The line *lengths* were probably drawn freehand; these lengths have an average deviation from their regression line of $\pm$ 7.4 mm. The line spacing, however, is quite good, the mean being 34.5 $\pm$ 2.0 mm, average deviation from the mean $\pm$ 3.4 mm, and is the same, within the statistical uncertainty, as spacing of the left-hand set.

(5) Measurement of a freehand drawing of the pictograph, scaled to match the enlarged print of Plate VIII, appears to confirm that except for the straight line and end positions of the right-hand count lines, the pictograph was painted without the use of guide lines or spacers. Generally, the variations in line length and spacing measured on the drawing were similar to, or somewhat smaller than, those in the pictograph. The larger values in the pictograph may have resulted from the painter having to paint the pictograph in a difficult location: on the ceiling of the overhang. In contrast, the deviation of the end points of the right-hand count lines from their regression line was much less, and the straight line noticeably straighter, in the pictograph than on the drawing, confirming that these features were painted using guide lines.

Measurement of freehand drawings shows that five-line sets with a spacing accuracy like that of the pictograph can be produced by drawing lines 1 and 5 and locating the others by bisecting and re-bisecting the interval between them. For a six-line set, line 6 is then added at the end. Since this line is not located by bisection, its spacing may differ from that of the others. In the right-hand line set, the line 5-6 spacing is 30 % greater than the mean of the other lines, differing from it by 8.9 σ. That inequality may then indicate that the line spacings were produced by the above method. Further indication that the two line sets were produced in this way is provided by the spacing of the five lines comprising the left-hand set. In this set, the distance between lines L1 and L5 matches closely the L2–L6 distance in the right-hand set, and is clearly greater than the L1–L5 distance in that set. This suggests that the right-hand set was painted first, and that the L2–L6 distance—which included the anomalously large L5–L6 separation—was then chosen as the distance between the end lines, L1 and L5, of the left-hand set. Lines L2, L3, and L4 of that set were then located using the bisection method.

That the above interpretation of this pictograph is correct would seem to be corroborated by the observers themselves: They placed a short, red-painted locator line, about 7 cm long, exactly half way between the "event-model" symbol and the adjacent 6½-line pictograph, discussed above, and pointing from the one to the other, as shown in Figure 12. The observers thus show us that the two panels are (1) related, and (2) refer to the sun near the time of the summer solstice: The 6½-line panel is the accurate record of their timing of the summer solstice, while the "event-model" symbol illustrates the reasoning by which they justified retaining the traditional rule of celebrating the solstice on the seventh day that the sun rose in the solstice notch.[3]

Two of the sun symbols in the overhang may also record the change from $N = 13$ to $N = 12$. If one wishes to simply draw a circle—or ellipse—with equally spaced rays, the easiest way to do so is to bisect and re-bisect the circle, placing rays along the bisection lines, and repeating the process until an artistically pleasing set of rays has been generated. Sun symbols produced in this way will have 4, 8, 16, 32, 64, etc. rays.[4] In symbols with these numbers of rays, it is unlikely that the number of rays has any particular significance—beyond that of showing that the symbols were, in fact, constructed using the bisection method. Two of the Shelter Rock sun symbols are of this type:

(1) The large ceiling sun symbol shown in Figures 2 and 15 consists of two concentric ellipses, as discussed above. These ellipses are made up of dots or short rays, the inner ellipse having, as near as one can tell, 16 such features, and the outer, 32.

(2) The sun (or sun-like) symbol, shown at the bottoms of Figures 8 and 9, consists of two concentric circles, each composed of 16 dots.

In contrast, two other symbols appear to have 12 rays. These are the rear-wall sun symbol shown in Figures 1 and 3, and the ceiling sun (or sun-like) symbol reproduced in Figures 8 and 10.

The sun symbol in Figures 1 and 3—a circle with external rays— was noted by Rafter as having 11 rays. However, the enhanced-color technique described earlier reveals what appear to be the faint traces of a twelfth ray. This feature is best shown in Figure 1, where it occurs just above the broad, dark ray on the right-hand side of the symbol. Analyzing the symbol, it appears that in this instance the painter first bisected the circle vertically and horizontally, as viewed in Figure 1. He then bisected the four resulting quadrants, placing rays more or less along each of these bisection lines, giving a total of eight reasonably well-spaced rays. He then bisected four of the octants resulting from the previous bisections, to locate the final four rays. The octants bisected were those adjacent to the original horizontal bisection line. The result was a symbol that has 12 rays, with symmetry about the vertical and horizontal bisectors (as seen in Figure 1), but with non-uniform spacing, the spacing between successive rays being greater at the top and bottom of the symbol than on the sides.

The ceiling symbol, shown above center in Figure 8 and in Figure 10, resembles the one shown in Figures 8 and 9, discussed above. This symbol consists of a

Figure 13. Detailed view of seven-line symbol shown in Figures 11 and 12. Southeast at top, northeast at right of figure. See text. Scale bar = 20 cm.

Figure 14. Pictograph on ceiling near north end of Shelter Rock overhang, depicting motion of sunrise point near the summer solstice. Southwest at the top and southeast to the right of the figure. See text. Scale bar = 10 cm.

circular pattern of short rays, each about 3 cm in length. There is some indication that the ends of these rays may have originally lain along the circumferences of two concentric circles. The number of rays is somewhat uncertain, but from the spacing of the better preserved features, appears to have been 12. This symbol appears to have been constructed by first bisecting the circle(s) twice to form quadrants, and then dividing these quadrants roughly into thirds.

Owing to the extra effort required to produce fairly evenly spaced sets of 12 rays, it seems possible that this was undertaken because that number of rays was of particular significance. The decrease in N from $N = 13$ to $N = 12$ might well have been considered worthy of being recorded in the number of the sun symbol's rays. That the number of rays in a sun symbol might represent day counts has been suggested previously by Rafter (1993), who described three sun symbols at site SBCM 1524–E. One of these symbols has 10 rays, while the other two each have 14. According to Rafter, the numbers of these rays were day counts which, together with the linear set of count lines mentioned earlier, were used to indicate the number of days from mid spring to the summer solstice (mid spring being found by dividing in two the number of days from the equinox to the solstice).

Of course, time marched on and N continued to decrease, reaching $N = 11^{\mathrm{d}}\!.5$ about A.D. 1750, $N = 11^{\mathrm{d}}\!.0$ around 1830, $N = 10^{\mathrm{d}}\!.5$ about 1910 and $N = 10^{\mathrm{d}}\!.0$ around 1980. Yet, there is no record in the pictographs of any further change in N or adjustment of the date of the solstice celebration. While a number of other sets of possible count lines exist in the overhang, no sets definitely containing only six or five lines are found. Nor do we find sun symbols that clearly display fewer than 12 rays. Thus, if the foregoing interpretation is correct, it would appear that by a date somewhere between about A.D. 1610 and 1750 the old traditions were no longer being observed.

And still the decrease in N continues, at an ever increasing pace, so that after about A.D. 2650 the sun will no longer rise in the horizon V, and will not do so again for another 20,000 years (Berger 1988; Laskar et al. 1993). Yet, all is not lost. If anyone still wishes to witness the spectacle of the sun rising in the solstice notch after A.D. 2650, they have only to shift their observing point a short distance to the north of Shelter Rock. The appearance of the notch will of course be somewhat different, but it may still be possible to get an impression of what the ancient observers—and the writer—witnessed so long ago.

Although there is no evidence that summer solstice observations were made at Shelter Rock after about A.D. 1610–1750, there is some indication that such observations may have been made, at least for a time, before A.D. 1450, when the solstice sunrise still occurred north of the solstice notch. As can be seen in Figure 15, the eastern portion of the ceiling of the Shelter, in the vicinity of the elliptical sun symbol, is covered with a multitude of red pictograph markings. Buried within this tangle of dots, lines and curves, several sets of short parallel lines can be discerned which may possibly be count lines. The numbers of the lines in these sets are somewhat uncertain, owing both to fading of the lines as

Figure 15. Photograph of ceiling near north end of Shelter Rock overhang, showing relative positions of the pictographs in Figures 2 and 14. West at the top and south to the right of the figure. See text. Scale bar = 40 cm.

Figure 16. Pictograph on ceiling at north end of Shelter Rock overhang. Southeast at the top and northeast to the right of the figure. Pictograph shows that the sun rises in the solstice notch for six days before and five days after the day of the summer solstice. See text. Scale bar = 10 cm.

a result of weathering, and to the overlapping of other pictographs. However, in the two clearest sets, these numbers appear to be 9–10 and 9 respectively: Just to the left of the sun symbol in Figure 15 are two parallel sets of lines, each apparently having had originally at least 9 and, in one case, probably 10 lines. (The right-hand set of lines appears to have three lines missing from the middle of the sequence, possibly erased to make room for rays from the elliptical sun symbol.) Immediately above this double set are traces of what may have been a second double set, or possibly a continuation of the double set of 10. Directly above the sun symbol, near the top of the figure, is another set of 9 lines. This set may also have originally been doubled, the second set, seemingly contaminated by overlapping marks, being located just to the left of the first. Both of these sets extend along lines parallel to the major axis of the elliptically shaped sun symbol which, as we have seen, is directed towards the summer solstice notch. This alignment further suggests that these count marks, like the sun symbol, are related to observations of the summer solstice sunrise.

These (doubled) sets may thus be the observers' records of the numbers of days from the first appearance of the sunrise point in the solstice notch to the day of the solstice; the individual lines of marks cannot denote N, since $N = 9\overset{d}{.}8$ at the present time, and was larger in the past. However, one line of marks could count the days as the sun approached the solstice, and the other (parallel) line the days as it receded from it. If we suppose that the number of count marks in each line of the double set is 10, then $N = 19$ or 21, depending on whether the 10th line represented the day of the solstice, or the day preceding the solstice; both systems of marking may have been used on occasion, as discussed above and in the next section. From Table 1, we see that $N = 21$ from about 500–300 B.C., $N = 19$ from about A.D. 130–350. Thus this set of count marks would suggest that solstice sunrise observations were being carried out at Shelter Rock sometime between 500 B.C. and A.D. 350. Observations may have been made even earlier if the faint lines just above the double 10-line count represent an older, former extension of that count; this extension of the 10-line count might have been erased as N decreased with the passage of time. The second set of double lines has a clearly defined count of 9 lines, corresponding to $N = 17$ or 19. From Table 1, $N = 17$ from A.D. 610–800. Thus, this set of lines would suggest that sunrise observations were also being made sometime between A.D. 130 and 800. The absence of clearly identifiable sets of count lines corresponding to $N = 14$–16 would seem to indicate that after about A.D. 600–800, no further summer solstice observations were made at Shelter Rock until around A.D. 1450, as described above.

3

Winter Solstice at Counsel Rocks

As pointed out by Rafter (1987), Shelter Rock is not suitable as a location from which to observe the winter solstice sunrise. This is due to the facts (1) that the winter solstice sunrise point is not visible from within the overhang, and (2) that as viewed from the platform above the overhang, the sun rises above the top of the mesa referred to by Rafter (1987) as "Barrier Hill," which, near the winter solstice sunrise point, is quite featureless, making it difficult to accurately mark the daily progression of the sunrise point along its top.

However, Rafter (1985) suggests two locations at Counsel Rocks that might have been used to determine the date of the winter solstice. The first of these is at the northeast face of his Rock 6. As described by Rafter, when the observer stands in profile against a certain point along this rock face, the solstice sun emerges above the top of the mesa southeast of Counsel Rocks (Barrier Hill) in a right-angled notch in the rock face at the southeast end of a petroglyph line which extends northward along the side of Rock 6 from the notch to—and beyond—the observer's location. Observations by the writer indicate that this alignment could not have been used to determine the precise date of the solstice: the position of the sunrise point along the skyline is not accurately defined by the notch in the face of Rock 6, being very sensitive to the exact position of the observer's head. In addition, the daily motion of the sun is very small for some six days before and after the solstice (during which time $\Delta\,\delta_{\odot} = 0^\circ\,07'$). Thus, to determine the precise day of the solstice, it would have been necessary to observe the passage of the sunrise point past some reference point on the top of the mesa well before (and after) the solstice, as discussed in the previous section. However, just as seen from Shelter Rock, the top of the mesa is featureless, providing no reference mark for the location of a specific sunrise point. The alignment along the face of Rock 6 could, however, have been used for ceremonial purposes—or for a quite different purpose, which will be discussed in the fourth section.

Rafter's second suggestion is that the date of the solstice was determined by observing the sun setting in the bottom of a V-shaped notch in the top of the cliff west of Counsel Rocks, as viewed through the cleft between his Rocks 2 and 3, from a vantage point immediately east of the eastern side of Rock 3, as illustrated by Rafter (1985:Fig. F, 1991:Figs. 3 and 4). A photograph of this observing location is reproduced in Figure 17. The view of the skyline and V as seen through the cleft by the observer standing just east of Rock 3 is shown in Figure 18. Here, as the figures show, the features of the skyline provide good reference points with which to mark the motion of the sunset point. As pointed out by Rafter (1985:113–114, 1991:72), evidence that observations of the sun setting in the V were used to determine the solstice date is provided by three of the petroglyphs inscribed within cavities of Rock 3:

As illustrated by Rafter (1985:Fig. F, 1991:Figs. 1–3) and shown in the photograph reproduced in Figure 19, a petroglyph line runs along the eastern portion of the north side of the main Rock 3 cavity, ending at the east end of the north side at a point level with the observer's line of sight through the cleft to the V. At sunset, the eastern end of this line is touched by a ray of sunlight shining down through the cleft.

Within Rock 3, a "tunnel," shown in Figure 20, leads from the main cavity to an opening on the west side of the rock. A number of petroglyphs are inscribed in the floor of this tunnel. These are partially visible in Figure 20. A photographic panorama of the petroglyphs is reproduced in Figure 21, and a layout drawing of them is shown in Figure 22. As these figures show, there are, along the northern side of the tunnel floor, a seven-line zigzag pattern and an inverted V. These two petroglyphs, first noted by Rafter (1985:113–114), are illustrated by Rafter (1991:Fig. 5). As discovered by Rafter, near the date of the winter solstice and about one hour before local sunset, a band of sunlight, which enters the tunnel through the hole in the western side of Rock 3, lies with its leading edge along the westernmost line of the zigzag. This is illustrated in Figure 21, where the photograph shows the eastern edge of the sunlit area lying along the eastern side of this line. Then, as the sun approaches its setting behind the cliff west of Counsel Rocks, the leading edge of the band lies successively along alternate lines of the zigzag until it disappears just before reaching the easternmost line, a few minutes before sunset. During this interval, the sunlight band also reaches the inverted V, with its northern edge extending just to the apex of the V, and not progressing northward of this point. Following the disappearance of the sunlight at the zigzag, the inverted V remains illuminated for a short time, the sunlight then extending from just the apex to the southern ends of the V.

That the sunsets near the winter solstice were observed through the cleft from Rafter's position immediately east of Rock 3 is further confirmed by a low, rounded rock embedded in the ground just at this location. This rock, visible below the cleft in Figure 17, measures 28 cm east to west by 30 cm north to south at ground level, and has a maximum height of 13 cm. The western side of this rock consists of two plane surfaces with a slight convex angle between them. Experiment shows that, owing to this structure, if the observer stands on the ground west of this rock, facing the cleft, and then backs up until his feet first encounter, and then rest upon, the western side of the rock, left foot on the

Figure 17. Observer's station for observations of the winter solstice sunset. The observer stood at the heelstone, visible in the lower right corner of the figure, and observed, through the cleft between Rocks 2 (left) and 3 (right), the sun setting in the skyline V, visible here above the cleft. See text. Photographed on Fuji Provia 100F film.

Figure 18. Skyline V as seen through the cleft between Rocks 2 (left) and 3 (right) by observer standing on the western side of the heelstone shown in Figure 17, with a line of sight 163 cm above ground level. See text. Photographed on Kodak Plus-X film, no filter.

southern and right foot on the northern of these two planes, he will automatically be positioned so that he will see the skyline V centered, or very nearly so, in the cleft, as it appears in Figure 18.

That this "heelstone" (in the literal sense of the term) was used in this way is shown by the fact that the western side of the stone is noticeably less rough than the rest of its surface, or of the surfaces of the other rocks in the vicinity, having been worn smooth by the feet of generations of sunset observers. Such wearing of the surface is reasonable since the rocks at this site are composed of relatively soft volcanic tuff. This smoothing is illustrated in Figures 23 and 24. Figure 23 shows the heelstone viewed from the south. Figure 24 shows two views of the heelstone and two rocks located just to the east of it. Figure 24 (top) shows the rocks as seen from the west, and 24 (bottom) as viewed from the south. These two photographs again show that while the western side of the heelstone is relatively smooth, its eastern side is much rougher and is similar in appearance to the surfaces of the two rocks to its east; the surfaces of these two rocks are typical of those of the rocks in the surrounding area.

A closeup photograph of the zigzag pattern and inverted V (visible in Figs. 20–22) is reproduced in Figure 25. The lines of these petroglyphs, pecked into the rock surface, are about 10 mm in width. Numbering the lines of the zigzag from east to west, lines L4–L7 are all heavily worn, polished, stained and patinated in the same manner and to about the same degree as the lines of the inverted V and most of the other petroglyphs on the tunnel floor shown in Figures 21 and 22 and discussed below. Thus, all of these petroglyphs are clearly extremely old. Note, however, that the inverted V appears more worn than L4–L7 and may be somewhat older than the lines of the zigzag. On the other hand, lines L1 (except for the last 2 cm at its southern end), L2, and L3 up to a point about 15 mm east of the junction of L3 and L4, are much less worn and are less—though still slightly—patinated than L4–L7. The newer-looking appearance of these lines is evidently the result of the re-pecking of pre-existing lines: The depth of the less patinated portion of L3 is noticeably greater than that of the adjoining heavily patinated 15 mm continuation of that line and of the following line, L4. L7 is much shallower than the other lines, and is therefore shown by dots in Figure 22. In L7, the degree of patination is more difficult to assess, but appears to be similar to that of L4–L6. As shown in Figures 22 and 25, the more visible part of L7 is only about 8 cm in length. However, careful visual examination of this line reveals that a few peck marks are present which extend it northward by about another 2 cm; this extension is indicated in Figure 22 by the more widely spaced dots.

At first glance, the zigzag pattern appears rather irregular, even haphazard, in shape. This impression is enhanced by the facts (1) that the petroglyph is normally viewed at a considerable angle from the perpendicular to the rock surface, and (2) that the surface on which it is inscribed is not flat. However, a more detailed examination of the actual petroglyph and of both Rafter's (1991)

Figure 19. Eastern portion of north side of main cavity in Rock 3. View extends from north tunnel on the left to east end of Rock 3 on the right. Photographed on Kodak Plus-X film, no filter. Illuminated by natural light. Scale bar = 40 cm.

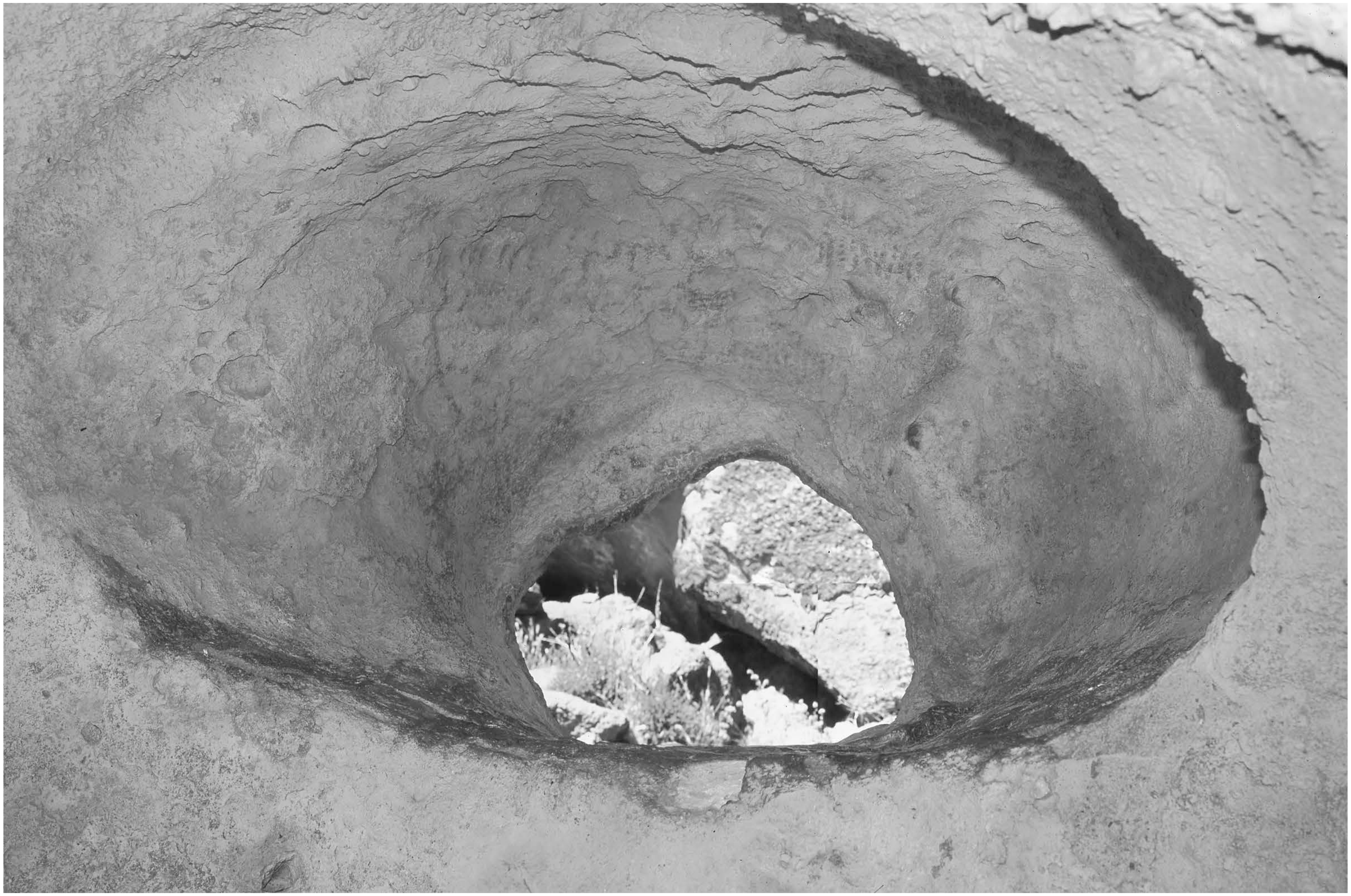

Figure 20. View within the main cavity of Rock 3, showing the west tunnel which extends to the west side of the Rock. Digital composite of four photographs, taken on Fuji Provia 100F film, and illuminated by flash unit mounted on camera. Width of tunnel opening 140 cm.

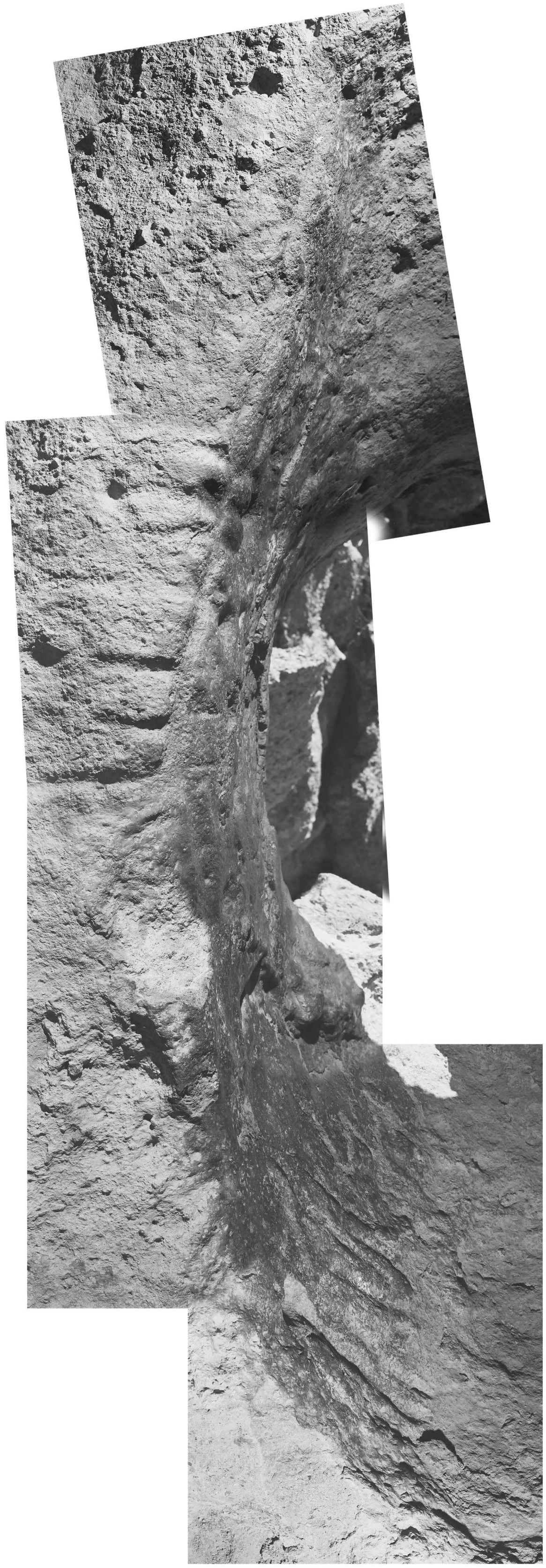

Figure 21. Panoramic view of petroglyphs inscribed in floor of the west tunnel in Rock 3 (Fig. 20). Digital composite of four photographs, taken on Kodak Plus-X film, no filter. Illumination by flash unit: to right of camera in right-hand photograph, to left in all others. In this view, the eastern edge of the band of sunlight which enters the tunnel during the afternoon lies along the westernmost line (L7) of the zigzag pattern. See text.

Figure 9 and Figures 22, 25 and 26 of the present paper reveals that the pattern was laid out with considerable care. First, with the exception of the southern ends of L2 and L3 and the northern end of L7, all of the north and south end points of the lines lie along, or very close to, two nearly parallel straight lines. (The north end of L7 also lies close to the extension of the line through the north ends of L1–L6, when the sparsely pecked northward extension of that line is included.) Second, as noted above, lines L7, L5, and L1 have been constructed so that they match the shape and orientation of the leading edge of the band of sunlight as that edge successively crosses, or approaches, each of these features.

In the present investigation, the progression of the leading edge of the band of sunlight across the zigzag pattern, and the inverted V, were studied both visually and photographically. Details of the visual observations are given in Table 2. Dates and times of the photographic observations are listed in Table 3. The positions of the leading edge of the sunlit band on these photographs were transferred to a copy of the photograph of the zigzag reproduced in Figure 25. The resulting overlay, showing the progression of the sunlit band across the zigzag, is shown in Figure 26.[5]

Figure 26 illustrates the fact, as discussed above, that lines L7 and L5 conform very closely to the shape of the leading edge of the sunlit band. The agreement of L7 with this edge is particularly striking. The leading edge of the sunlit area follows in both shape and length the eastern edge of L7, even in its larger irregularities, from the apex of its junction with L6 to the northern end of the more deeply engraved portion of L7.

The agreement with L5 is also very good over the entire length of that line, although now the sunlit edge extends well south of the L4–L5 junction. However, by the time that the leading edge reaches L3, the agreement is becoming significantly poorer: The edge lies along L3 from the L3–L4 junction to only about the midpoint of L3. And then, as the sunlit band continues eastward, its leading edge swings around so that by the time that it reaches the L2–L3 junction, it no longer lies along L3, but instead bisects the angle formed by L2 and L3. This new orientation persists as the sunlight moves on eastwards toward the junction of L1 and L2. As the edge approaches this junction, the sunlight begins to diminish in intensity at the zigzag, and vanishes completely at about the time that the leading edge reaches the junction; the edge of the sunlit band never reaches L1 itself. Just prior to its disappearance, the shape and direction of the leading edge are similar to those of L1, but with somewhat less curvature.

The locations of the lines of the zigzag pattern, and/or the points at which the successive lines intersect, appear to have been carefully chosen, and to be related to the visibility of the sun within the cleft between Rocks 2 and 3. Observations of the position of the sun within the cleft as functions of the date, time and observer's location are given in Table 4.

As the observer moves northward from his normal position at the heelstone, the width of the section of skyline visible through the cleft decreases to zero. At

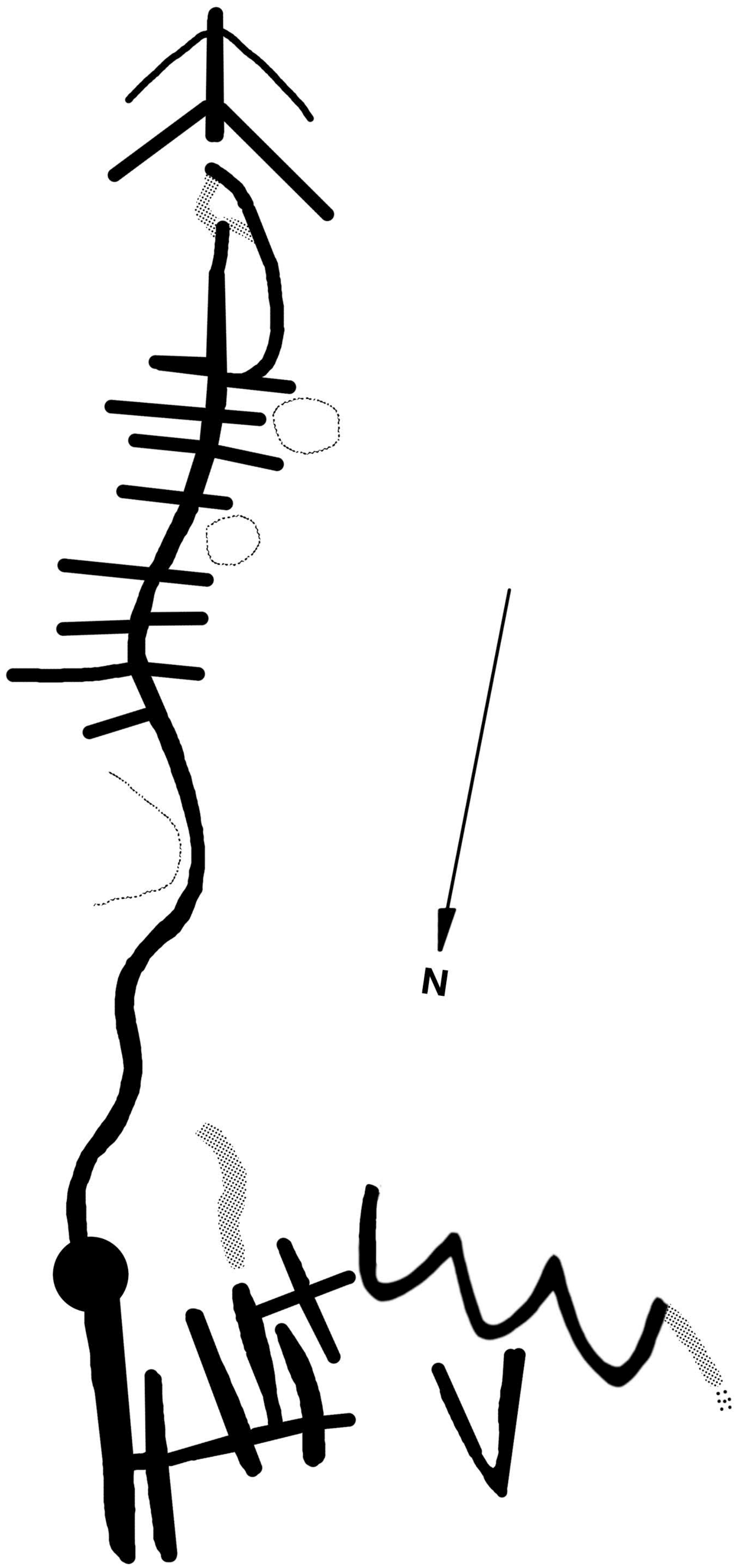

Figure 22. Layout drawing of the petroglyphs on the floor of the west tunnel in Rock 3. Shallower features indicated by dot patterns. Natural holes or spalls in or of the rock surface indicated by dotted lines. Length of north arrow (to tip) = 30 cm.

Figure 23. Heelstone, viewed from the south. East–west width of stone at ground level 28 cm. Photographed on Fuji Provia 100F film.

Figure 24. Heelstone and adjacent rocks to its east, photographed on Fuji Provia 100F film. Top: Viewed from the west. Bottom: Viewed from the south.

Table 2. Observed Times of Leading Edge of Sunlight Band at Features of Zigzag and Inverted "V"[a]

Date	Time PST	Location of Leading Edge of Sunlit Area
2006		
Dec. 09	$13^h36^m30^s$	Apex, L1–L2.
13	13^h15^m	Apex, L3–L4.
13	$13^h25^m10^s$	Apex, L2–L3.
13	13^h31^m	Midpoint, L2.
14	$13^h11^m05^s$	Apex, L5–L6.
14	$13^h18^m00^s$	Apex, L3–L4.
14	$13^h26^m00^s$	Apex, L2–L3.
14	$13^h38^m00^s$	Apex, L1–L2.
15	$13^h06^m30^s$	Apex, L5–L6.
15	$13^h17^m00^s$	Apex, L3–L4.
Dec. 15	$13^h26^m15^s$	Apex, L2–L3.
2007		
Dec. 09	$13^h36^m30^s$	Apex, L1–L2 ($\pm$ 15 sec).
10	$13^h05^m15^s$	Apex, L5–L6.
10	$13^h13^m20^s$	Apex, L4–L5.
15	$< 12^h45^m$	On L7.
15	12^h51^m	Apex, L6–L7.
15	13^h15^m	Apex, L3–L4.
15	$13^h25^m30^s$	Apex, L2–L3.
15	13^h32^m	Midpoint, L2.
16	12^h44^m	On L6 and at L5–L6 Apex.
16	12^h55^m	Midway between L5 and L6; Not yet at Apex, L5–L6.
16	13^h00^m	Nearly to west edge of L5. Edge matches curve of L5 for upper 2/3 of L5.
16	$13^h01^m30^s$	Apex, L5–L6, and at east side of L5.
16	$13^h06^m45^s$	Apex, L4–L5.
16	$13^h07^m00^s$	Apex, L4–L5.
16	$13^h16^m30^s$	Apex, L3–L4 ($\pm$ 15 sec).
16	$13^h17^m30^s$	Definitely past Apex, L3–L4.
16	13^h26^m	Apex, L2–L3 (Time accuracy uncertain).
16	$13^h39^m20^s$	Apex, L1–L2. Becoming faint.
Dec. 16	$13^h39^m45^s$	Apex, L1–L2. Fading.

Table 2—Continued

Date	Time PST	Location of Leading Edge of Sunlit Area
2007		
Dec. 17	$12^h41^m00^s$	About tangent to west side, L7. Follows L7 for its entire length.
17	$12^h42^m00^s$	Tangent to west side, L7.
17	$12^h43^m00^s$	On middle, L7.
17	$12^h43^m30^s$	Past center of L7.
17	$12^h44^m00^s$	At east edge, L7. Follows shape of line except for local irregularities.
17	$12^h45^m00^s$	Apex, L6–L7.
17	$12^h48^m30^s$	Midpoint, L6.
17	13^h02^m	Beyond east side of L5 at its midpoint.
17	$13^h03^m00^s$	Apex, L5–L6.
17	13^h06^m	Apex, L4–L5.
17	$13^h07^m00^s$	Apex, L4–L5.
17	$13^h11^m15^s$	Midpoint, L4.
17	$13^h16^m45^s$	Apex, L3–L4.
17	$13^h17^m30^s$	Bisects angle between L3 and L4.
17	$13^h39^m20^s$	Apex, L1–L2. Fading fast, except at inverted "V."
20	$12^h39^m00^s$	Approaching L7.
20	$12^h43^m00^s$	Bisects middle of L7.
22	$13^h04^m10^s$	Midpoint, L6.
22	$13^h19^m00^s$	Apex, L3–L4.
22	13^h20^m	Past L3–L4 Apex.
22	$13^h28^m30^s$	Apex, L2–L3.
23	12^h46^m	Slightly past L7 (Time approximate.)
23	$12^h54^m20^s$	Midpoint, L6.
23	$12^h54^m30^s$	Midpoint, L6.
23	$13^h10^m48^s$	Apex, L5–6.
23	$13^h12^m59^s$	Midpoint, L5.
23	$13^h13^m49^s$	Midpoint, L5.
23	$13^h17^m09^s$	Now difficult to see older portions of zigzag not yet in sun. Easy to see repecked lines L1–L3.
23	$13^h20^m35^s$	Apex, L3–L4.
23	$13^h26^m18^s$	At west edge of east branch of inverted "V." Matches entire length of east branch.
Dec. 23	$13^h27^m01^s$	Midpoint, L3.

Table 2—Continued

Date	Time PST	Location of Leading Edge of Sunlit Area
2007		
Dec. 23	$13^h28^m47^s$	At east edge of east line of inverted "V." Tracks line well for about south 3/4 of line.
23	$13^h30^m03^s$	Apex, L2–L3. Position somewhat uncertain due to diffuse edge of sun band.
23	$13^h30^m11^s$	Apex, L2–L3.
23	$13^h30^m27^s$	*Slightly* past L2–L3 Apex.
23	$13^h32^m01^s$	North edge of sunlit area at the Apex of the inverted "V."
23	$13^h36^m44^s$	Midpoint, L2.
23	$13^h40^m15^s$	Sunlit band starting to diminish in intensity.
23	$13^h42^m07^s$	Sunlight almost gone at zigzag; still visible at inverted "V."
23	$13^h42^m37^s$	Sunlight extends from Apex to lower ends of inverted "V."
23	$13^h43^m20^s$	Apex, L1–L2; *barely* visible.
Dec. 23	$13^h43^m41^s$	As above. Top to bottom of inverted "V" illuminated; west edge of sunlit band is far to west of west line of inverted "V."
2008		
Dec. 19	$13^h20^m30^s$	Just past L3–L4 Apex.
19	$13^h27^m25^s$	Approaching L2–L3 Apex.
19	$13^h34^m35^s$	Midpoint, L2.
21	12^h43^m	On middle, L7.
Dec. 21	12^h45^m	On east edge, L7.

[a] Visual observations except that on December 23, 2007 at $13^h30^m11^s$, which was estimated from the photographs, listed in Table 3, taken at $13^h26^m46^s$, $13^h30^m11^s$, and $13^h32^m23^s$.

Table 3. Photographic Observations of Sunlit Band on Zigzag Pattern and Inverted "V"[a]

Date	Time PST
2007	
Dec. 22[b]	12^h32^m
23	$13^h10^m54^s$
10[c]	$13^h13^m20^s$
23	$13^h20^m54^s$
23	$13^h26^m46^s$
23	$13^h30^m11^s$
23	$13^h32^m23^s$
23	$13^h36^m56^s$
23	$13^h42^m26^s$
Dec. 10[c]	$13^h36^m40^s$

[a] Dates and times of the photographic observations used in constructing Figure 26. All observations are listed in order of their appearance in Figure 26 from left to right.

[b] Time approximate, between 12^h32 and 13^h05.

[c] Shown as dashed line in Figure 26.

the same time, the moment at which the preceding limb of the sun first appears in the cleft becomes earlier. Thus, the earliest view that the observer can have of the sun in the cleft is that which he sees from the point where only a tiny bit of the skyline is still visible through the cleft. From Tables 2 and 4, we see that this time matches closely the time that the leading edge of the band of sunlight reaches L7. The position of the westernmost line of the zigzag may therefore have been chosen to mark this event. If both L7 and the L1–L2 junction mark significant events during the approach of sunset, might the other lines, or line-junction points, do so as well?

Of particular interest is L3 and its intersection with L2. As noted above, the odd-numbered lines—L7, L5, and L1—all match at least approximately the shape of the leading edge of the band of sunlight. Yet L3 does not. Since the shapes of L7, L5, and L1 do match, the fact that L3 does not can hardly be accidental, but must have been intended. Also, the southern ends of L2 and L3

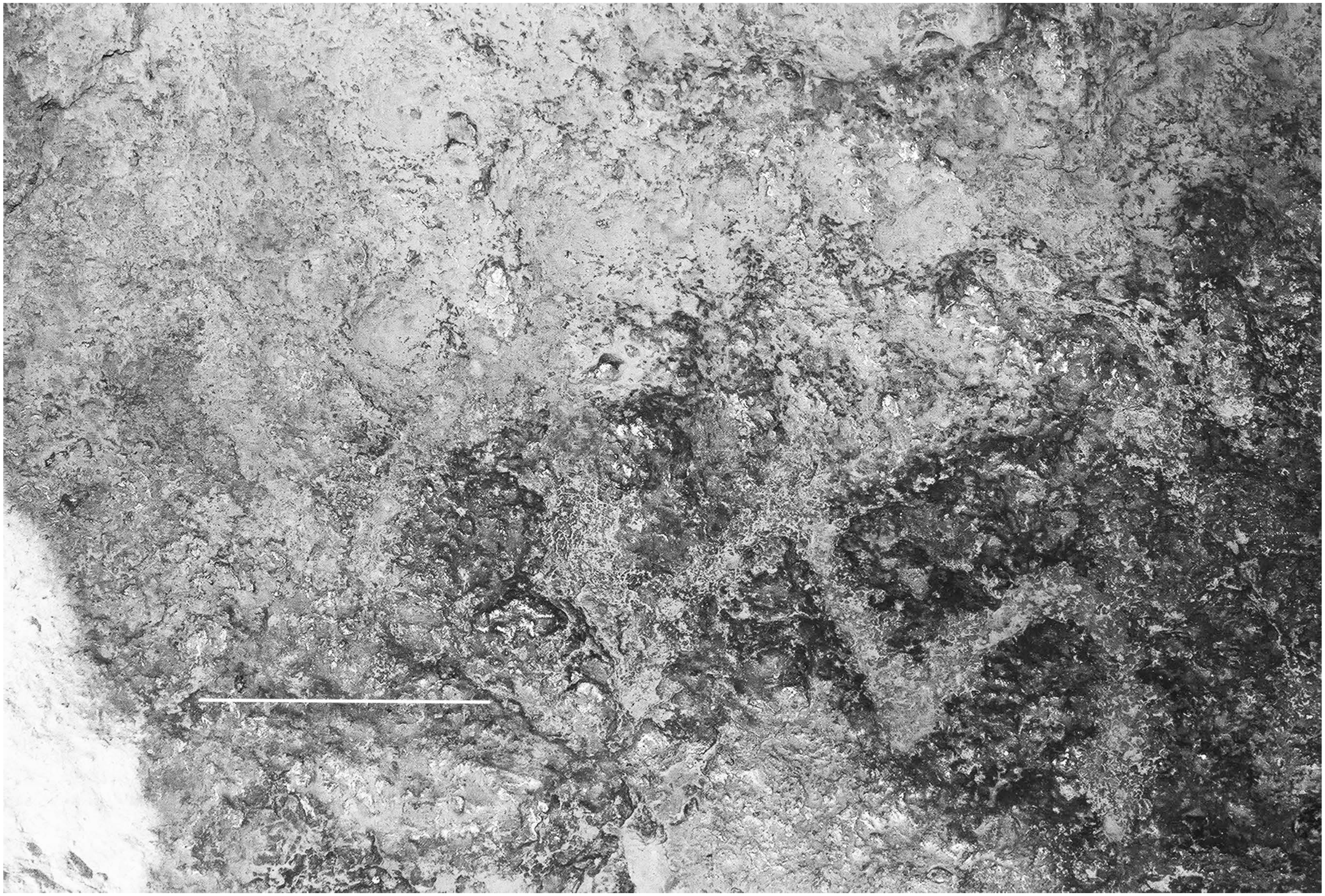

Figure 25. Zigzag petroglyph in west tunnel of Rock 3. Photographed on Kodak Plus-X film, no filter. Illuminated by flash unit mounted on camera. Photograph taken 2007 December 22 12:32 PST. Shows sunlight band entering on left. Scale bar = 10 cm.

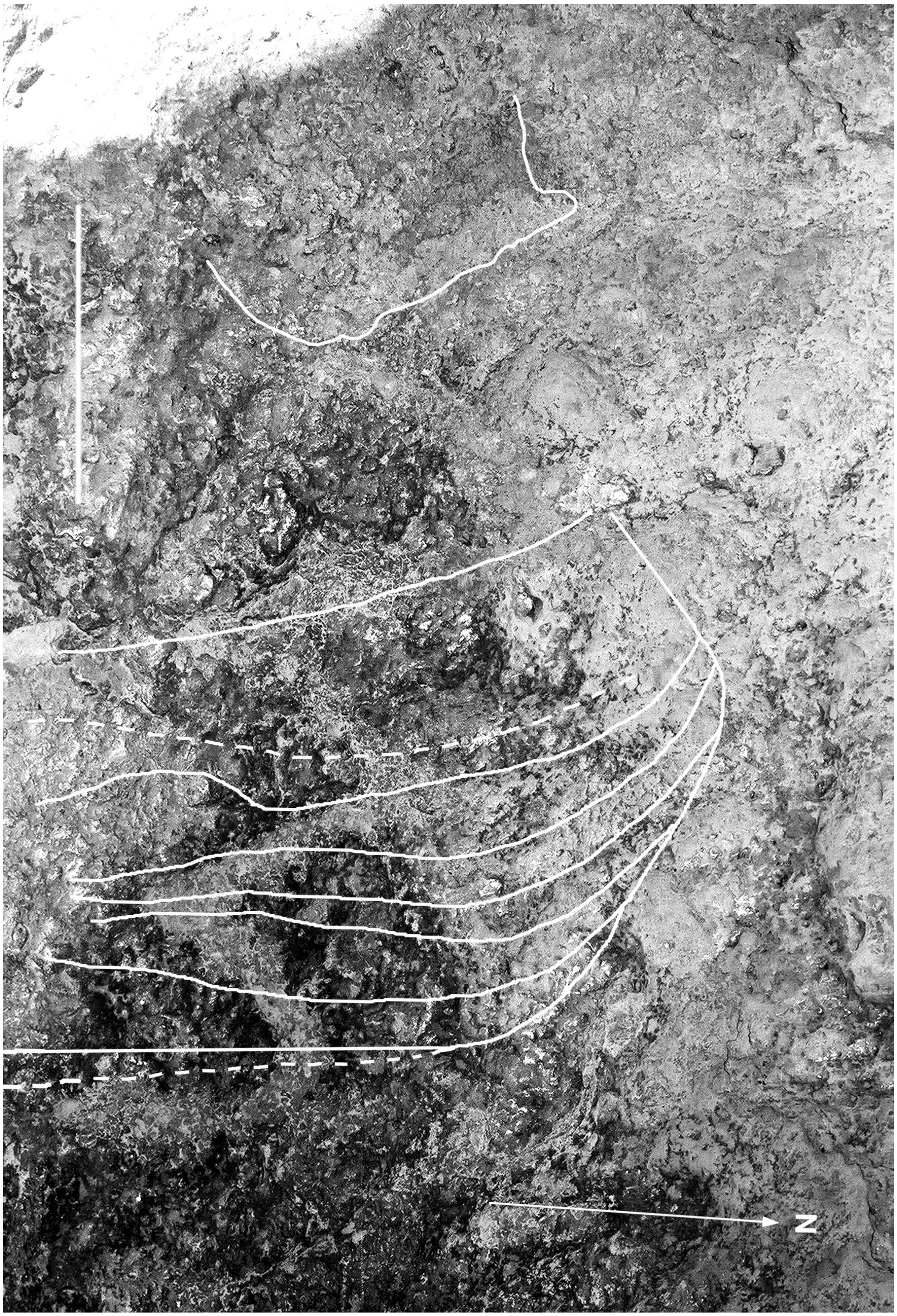

Figure 26. Counsel Rocks: Zigzag petroglyph (Fig. 25) showing progression of eastern edge of sunlit band across the pattern, traced from photographic observations. Dates and times of these observations are given in Table 3. Dashed lines indicate observations on December 10, 2007; all others made on December 22 or 23, 2007. Scale bar = 10 cm.

Table 4. Position of Sun in Cleft[a]

Date	Time (PST)	Position of the Sun
2007		
Dec. 11	$13^h41^m08^s$	Sun 1/2 way behind north side of V.
11	$13^h41^m50^s$	Sun 2/3 way behind north side of V.
12	$13^h40^m45^s$	Sun 1/3 way behind north side of V.
12	$13^h42^m05^s$	Sun 1/2 way behind north side of V.
12	$13^h42^m16^s$	Sun 3/4 way behind north side of V.
13	$13^h40^m50^s$	Sun tangent to north side of V.
13	$13^h41^m40^s$	Sun 1/3 way behind north side of V.
13	$13^h42^m15^s$	Sun 1/2 way behind north side of V.
14	$13^h42^m48^s$	Sun 1/3 way behind north side of V.
14	$13^h43^m19^s$	Sun 1/2 way behind north side of V.
14	$13^h43^m34^s$	Sun 3/4 way behind north side of V.
15	13^h06^m	Sun enters cleft, standing north of heelstone where cleft closes.
15	13^h23^m	Sun not yet in cleft.
15	13^h25^m	Preceding limb of sun enters cleft.
15	$13^h34^m30^s$	1/2 of sun's disk in cleft.
15	$13^h36^m00^s$	Sun's disk just completely in cleft.
15	$13^h38^m35^s$	Sun centered in cleft.
15	$13^h42^m08^s$	Sun tangent to north side of V.
15	$13^h42^m30^s$	Sun 1/3 way behind north side of V.
15	$13^h42^m48^s$	Sun 1/2 way behind north side of V.
15	$13^h43^m14^s$	Sun 1/2 way behind north side of V.
16	$13^h08^m30^s$	Sun tangent to south side of cleft, viewed from north of heelstone where cleft closes.
16	$13^h26^m27^s$	Sun's preceding limb just in cleft. Entry time not observed.
16	$13^h36^m45^s$	Sun 1/2 of sun's disk in cleft.
16	$13^h38^m46^s$	Sun well centered in cleft.
16	$13^h42^m47^s$	Sun tangent to north side of V.
16	$13^h43^m58^s$	Sun 1/2 way behind north side of V.
16	$13^h44^m12^s$	Sun 1/2 way behind north side of V.
17	$13^h43^m57^s$	Sun 1/2 way behind north side of V.
Dec. 19	$12^h44^m26^s$	Sun just visible in cleft from north of heelstone where cleft closes. May be visible slightly earlier.

Table 4—Continued

Date	Time (PST)	Position of the Sun
Dec. 19	12^h59^m	Sun just visible when standing on ground north of heelstone, where cleft closes. Sun appears in notch formed by irregularities in south side of cleft.
19	13^h00^m	Sun just visible when standing on ground north of heelstone, where cleft closes. Sun appears in notch formed by irregularities in south side of cleft.
19	13^h18^m	Sun not yet in cleft.
19	13^h21^m	Sun enters cleft if observer stands in standard position at heelstone and sways to right to where bottom of V is occulted by Rock 3 forground.
19	13^h25^m	Sun about same. Sun is following south edge of cleft and stays just out of sight as viewed from "standard" position.
19	$13^h45^m02^s$	Sun about 1/2 way behind north side of V.
20	$12^h43^m00^s$	Too cloudy to see sun from north of heelstone.
20	$13^h42^m08^s$	Sun completely in cleft.
20	$13^h45^m53^s$	Sun about 1/2 way behind north side of V.
21	$13^h26^m45^s$	Sun first appears in cleft.
21	$13^h41^m14^s$	1/2 of sun's disk visible in cleft.
21	$13^h42^m37^s$	Sun now tangent to south side of cleft.
22	13^h05^m	Sun in cleft, where cleft closes.
22	13^h23^m	Sun in cleft standing as on Dec. 19, 13^h21^m PST.
22	13^h27^m	Sun enters cleft.
22	$13^h28^m30^s$	Sun enters cleft for observer at the heelstone with eye at the minimum height of 148 cm above ground level.
Dec. 24	$13^h30^m25^s$	Sun enters cleft.

Table 4—Continued

Date	Time (PST)	Position of the Sun
2008		
Dec. 19	$12^{h}48^{m}$	Sun well into cleft from north of heelstone where cleft closes. Probably appeared $\simeq 12^{h}44^{m}$ as in 2007. Sun then skims along top of lower part of cleft and disappears.
19	$12^{h}57^{m}30^{s}$	Sun reappears in lower, straight section of south side of cleft, for observer standing where this section of cleft is *just* open—all the way down to the Skyline V.
20	$12^{h}40^{m}30^{s}$	Sun enters cleft standing north of heelstone, where the cleft closes.
Dec. 21	$12^{h}45^{m}$	Sun first appears at top of cleft, north of heelstone where the width of the section of skyline visible through the cleft decreases to almost zero.

[a] As seen by observer standing at the heelstone, with eye 163 cm. above ground level, unless otherwise noted.

do not lie along the straight line through the southern ends of L1, L4–L7. Since the northern ends of L1–L6 also lie along a straight line (which, as discussed above, is—in addition—nearly parallel to the line through the southern ends), the deviation of the southern ends of L2 and L3, and of their intersection point, would also appear to have been deliberate. If this intersection point was designed to mark some specific event in the run-up to the moment of sunset, that event was evidently considered to be of overriding importance, since its timing justified destroying the regularity of the zigzag pattern in order to accurately mark its occurrence. That the concept of regularity was important to the inscriber of the zigzag is shown by the layout of the other line ends. As we have seen, except for the southern ends of L2 and L3 and the northern end of L7, the ends of the zigzag lines lie along two nearly parallel straight lines. As already noted, the deeper, more visible part of L7 was constructed to closely match the length and shape of the leading edge of the band of sunlight. However, doing this left L7 too short to connect with the extension of the straight line through the northern ends of L1–L6. So, the inscriber very lightly pecked in an extension of L7, sufficient to bring its northern end at least approximately into line with the ends of the other lines, thereby preserving both the regularity and the scientific accuracy of the zigzag pattern. This extension is most clearly seen by direct visual examination, but can just be discerned in Figures 25, 26, 29, and 30.

The importance of the"L2–L3" event is also indicated by the fact, discussed above, that L3 does not lie along the direction of the leading edge of the band of sunlight as do L1, L5, and L7, but instead makes an angle of some 30° with that edge, with the result that when the band edge is at the apex of the L2–L3 junction, the edge of the band lies roughly half way between L2 and L3 over their entire lengths. Observation of the passage of the sunlight band across the zigzag pattern suggests that L3 and L2 may have been laid out as they are in order to increase the accuracy with which the time of the event of interest could be predicted. Owing to the diffuseness of the edge of the sunlit band, a more accurate time can be determined by noting its bisection of an angle, such as that formed by the junction of L2 and L3, than by attempting to judge when the edge of the band has aligned along a single line, such as L7 or L5.

Observing the sunlit band as it traverses the zigzag, it also becomes clear why the lines L1–L3 were repecked: when the leading edge of the band first arrives at L7, the intensity of the light within the sunlit area is not very great, so that it is relatively easy to see lines L6–L1 which are still in shadow. However, by the time that the band's eastern edge has reached the north end of L3, the glare of the light from the band has become so intense that the original, heavily stained and patinated, lines are no longer visible in the shadow. Thus, L1, L2, and most of L3 were likely repecked in order to enhance their visibility while they were still illuminated only by the diffuse light within the tunnel, ahead of the advancing band of sunlight, thereby facilitating the determination of the times:

(1) When the edge of the band arrives at the L2–L3 apex, and bisects the angle between L2 and L3.

(2) When the edge reaches, or is about to reach, the L1–L2 junction.

If we now examine Tables 2 and 4, we see that this critically important event, occurring when the leading edge of the band of sunlight bisects the L2–L3 angle, was the first appearance of the preceding limb of the solar disk in the cleft as seen by the observer at the heelstone.[6] Anticipating this moment was indeed important, if not for ceremonial reasons, then at least to the sunset observer, as it provided him with a warning that it was now no longer safe to look up through the cleft toward the sun, at least without some form of eye protection, since to do so now risked temporary blindness from accidentally gazing directly at the solar disk.

The purposes, if any, of the alignments of the preceding edge of the sunlight band with L5 or with the L3–L4 junction are less clear. Tables 2 and 3 indicate that the alignment with L5 occurs at about the time that the observer, standing on the ground north of the heelstone at the point where the cleft has almost closed, as described above, sees the following limb of the sun tangent to the south side of the cleft between Rocks 2 and 3. Thus, the L5 alignment might have been intended to mark this event. In addition, the tables show that the sun band reaches the apex of the L3–L4 junction at about the time that the sun enters the cleft as viewed by the observer standing on the ground with his left foot against the north side of the heelstone. In any case, if L5 and/or the L3–L4 junction do mark specific events, these events were evidently less important, and did not need to be as accurately timed as the L2–L3 event, since no modifications of the zigzag pattern were made to accommodate them.

Rafter (1991:Fig. 5) and Figure 26 show that after passing L7, the northern edge of the sunlit area moves northeastward to the apex of the L5–L6 junction, and then on to the northern tip of the inverted V. The northern end of the leading edge of the sunlit band then turns and progresses southeastwards, while the band maintains its same northern limit from the L5–L6 apex to the tip of the inverted V. The time that the leading edge arrives at the westernmost part of the V (the southern end of its western branch) was not recorded, but evidently occurs around the time that the sun first appears in the cleft to an observer with his eye point 163 cm above the north-side base of the heelstone.

More importantly, the figures show that the leading edge of the sunlit band lies closely along the entire length of the eastern edge of the eastern branch of the inverted V at the same moment that it passes through the vertex of the angle formed by L2 and L3 in the zigzag. Thus, the emergence of the eastern branch of the V into the sunlight marks the same event as does the zigzag, namely the appearance of the sun in the cleft as observed at the heelstone. That this event was marked not only by the zigzag but also by the inverted V is further testimony to its importance. As discussed above, the V may be older than the zigzag, and may thus represent an earlier, less elaborate and possibly less precise, means of timing this event.

The inverted V may also have been used to anticipate the moment of sunset. As indicated by Table 2, the sunlight disappears at the V about 2 minutes after it vanishes at the zigzag, and, at the moment of its disappearance, extends almost exactly from the northern tip to the southern ends of the two sides of the V.

The geometry of the skyline near the winter solstice sunset point is illustrated in Figure 27, which is a tracing from a photograph taken, like that reproduced in Figure 18, from the observer's position at the heelstone. The figure shows the skyline as seen through the cleft between Rocks 2 and 3, whose edges are shown shaded in the figure. The horizontal line is a level line, established from a plumb line in the original photograph. As the figure shows, the skyline V is actually not a "V," but instead consists of a vertical cliff, and a horizontal-to-slightly rising segment of skyline extending southward from the base of that cliff.[7] The fact that the cleft between Rocks 2 and 3 is not vertical, but is inclined towards the south, causes the observer to perceive this right-angled notch as a V, as it is depicted in Rafter's sketches (Rafter 1985:Fig. F, 1991:Fig. 4), and it will be

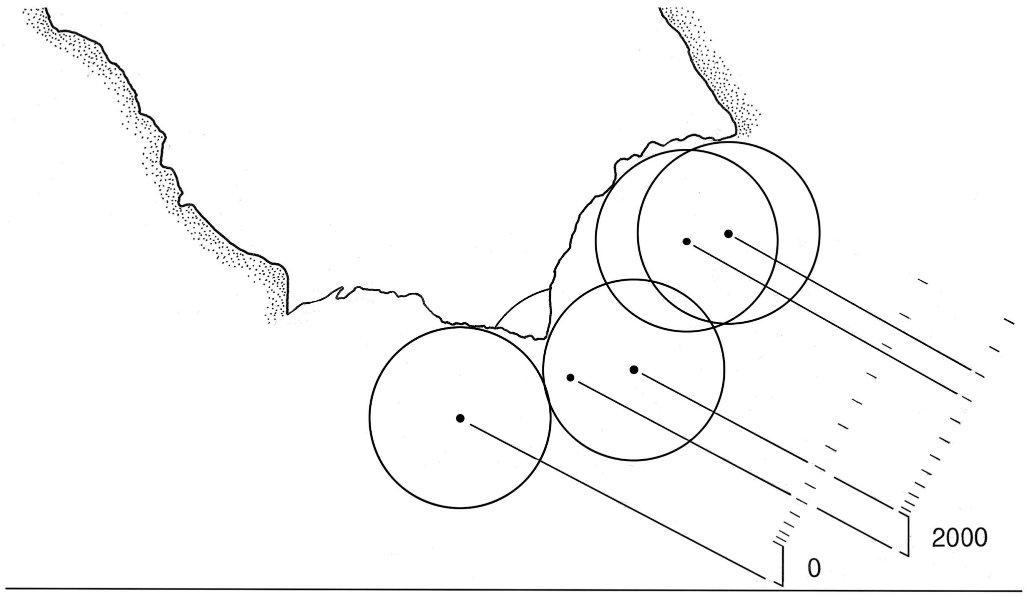

Figure 27. Counsel Rocks: Geometry of the winter solstice sunset as seen from the observer's position at the heelstone. Figure shows skyline as seen through the cleft between Rocks 2 and 3, whose edges are shown shaded. Horizontal line is a level line. Circles and arc represent the solar disk, 32′ in diameter. Centers of the disk are indicated by dots, and the diurnal paths of the disk centers by the inclined lines. The two sets of tic marks show the locations of the path of the center of the solar disk 0, 2, 3, 4, etc. days before the winter solstice in A.D. 01 (labelled "0") (left) and A.D. 2007 (labelled "2000") (right). The position of the skyline in the cleft, the three right hand circles and path lines, and the tic marks correspond to a line of sight 163 cm above ground level at the heelstone. For the minimum eye height of 148 cm, the two left most path lines, dots, the left-hand circle and arc show the position of the sun at the winter solstice in A.D. 01 (labelled "0") (left) and A.D. 2007 (labelled "2000") (right). See text.

referred to as a V throughout this paper. The cliff, along whose top the V is located, is situated at a horizontal distance of 64.6 ±0.3 m from the observer's position at the heelstone, and a line-of-sight distance of 70.8 m, determined using a surveyor's transit and measured baseline. Owing to the proximity of the skyline to the observer, a fairly small shift in the position of the observer's eye produces a significant change in the location of the sunset point along the cliff. Experiment shows that the skyline V begins to appear off-center in the cleft with a lateral displacement of the eye of about 5 mm from the optimum position, owing to the fact that the edges of the cleft are located at a distance of only about 3.7 m ahead of the eye point. This displacement corresponds to a horizontal displacement of the solar disk of only $0\overset{\prime}{.}2$ along the skyline. Displacing the eye laterally by 5 cm brings the bottom of the V to the edge of the cleft, but even in this case the displacement of the solar disk along the skyline is only $2\overset{\prime}{.}4$. However, in the vertical direction the displacement can be larger, since it depends both on the height of the observer and on his position along the line of sight to the skyline, neither of which is tightly constrained.

The circles in Figure 27 represent the solar disk, 32′ in diameter, just after the moment of sunset of the upper, or following, limb. The centers of these symbols are indicated by dots, and the diurnal paths of the sun are shown by the inclined lines. The tic marks indicate the locations of these paths 0, 2, 3, 4, etc. days before the winter solstice, as seen by an observer standing on the western half of the heelstone as described above, with his eye 163 cm above ground level and 98 cm east of the eastern edge of Rock 3. The right-hand set of marks, labeled "2000," indicates positions in A.D. 2007; the left-hand set, labeled "0," incidates positions in A.D. 01. The three right-hand circles indicate (from left to right) the positions of the solar disk at the winter solstice and 10.0 and 11.0 days before the solstice in A.D. 2007, based on photographs of the sunset taken between December 9 and 22, 2007 (UT), and December 19–21, 2008 (UT). These photographs (of the solar disk, partially occulted by the skyline) were made on Kodak Plus-X film at 1/500$^{\text{th}}$ of a second, f/32, and through a Schott NG 10 filter 2.0 mm in thickness.

Figure 27 predicts, and observations confirm, that as the sun approaches the winter solstice, it first moves uniformly along the skyline north of the V. Then, it "jumps" over into the V—just as does the summer solstice sunrise point at Shelter Rock, discussed in the previous section. Owing to the different geometry of the sunset skyline at Counsel Rocks, the "jump" is not as spectacular as that at Shelter Rock. However, it is still well defined, and in the past was even more so, due to the then larger daily motion of the sun in declination at the time of this event.

As Figure 27 shows, at the winter solstice, the sun now sets near the bottom of the V. As seen with the line of sight indicated above, the last bit of the solar limb disappears just to the north of the bottom of the V. However, this sunset point can be shifted southwards by lowering the observer's line of sight to the V. As the line of sight is lowered, the view of the bottom of the V is finally occulted by a southward projection of the east side of Rock 3. This feature is visible in Figures 17, 18, and 28. Standing as described above, at the heelstone, the minimum possible height of the line of sight to the bottom of the V is 148 cm, which occurs when the eyepoint is displaced vertically downwards from the normal viewing height of 163 cm illustrated in Figure 18. Owing to the northward-descending slant of the south side of the cleft, the bottom of the V is then just north of the south side of the cleft. This aspect is illustrated in Figure 28. The effect of this displacement is to lower the diurnal track of the solar disk by about $\Delta\ h = 07'$, which then causes the sunset point to lie almost precisely at the bottom of the V, as reported by Rafter (1985, 1991). In Figure 27, the two left-most inclined lines and dots and the corresponding circle and arc of the solar disk show the positions of the sun at the winter solstices in A.D. 01 and A.D. 2007 when the line of sight is lowered to this minimum value. As Figure 28 shows, observing at the minimum position provides an eyepoint whose position is very precisely located both vertically and horizontally. It is likely, therefore, that the observers used this viewing position when the sun set at or near the bottom of the V in order to minimize error due to the location of the eyepoint.

The observed times of upper or following limb sunset are listed in Table 5. These are the visual observations of the disappearance of the solar disk, observed either through the camera finder and NG 10 filter, or directly, through a No. 14 welder's filter, and along a line of sight 163 cm above ground level, except on December 21, 2008, when the minimum sight-line height of 148 cm was used.

In 2006, the sunset times were derived by counting seconds from the observed time of sunset until the clock could be read. This interval was sometimes as much as 10 to 20 seconds. The clock corrections were determined by comparison with the GPS clock, and were accurate to about one second.

In 2007, the times of sunset were noted orally on a tape recorder. GPS clock times were recorded on the tapes before and after the sunset observations. However, variations in the speed of the recorder tape during both recording and playback introduced some error into the recorded sunset times. These errors were estimated by deriving the sunset times from two separate playbacks of the tapes, and were found to be typically of the order of 1–2 seconds. These errors are probably smaller than the observational error which, in some instances, could be as much as several seconds since the visual monitoring of the sunset was not continuous, having been interrupted by the taking of the photographs.

As Table 5 shows, the sunset times are relatively constant before the sunset point enters the V, and then become progressively later as that point descends the north side of the V to its bottom. Comparison of these times with those given in Tables 2 and 4 indicates that the time of the appearance of the sun in the cleft and of the arrival of the sunlit area at the various features of the zigzag both vary with date in nearly the same manner as the sunset time. Thus, during the entire time that the sunset point lies within the skyline V, the warnings given by the arrival of the sunlight band at the various features of the zigzag always occur at about the same number of minutes before the moment of sunset as observed at the heelstone. During this time, the leading edge of the band arrives at the L2–L3 junction about 19 minutes, and at the L1–L2 junction about 6 minutes before sunset at the heelstone; as noted above, the sunlight disappears slightly later at the inverted V, about 4 minutes before the heelstone sunset.

As indicated above, observing the position of the sunset point along the skyline is much more difficult than determining that of the sunrise. At sunrise, the location of the point where the upper limb first emerges is easily seen in the moments before the eye becomes dazzled by the increasing intensity of the sunlight. At sunset, the eye is temporarily blinded by the glare of the solar disk, so that the skyline features are invisible at the moment of upper limb sunset.

Using the heelstone, the observer could place himself in the proper viewing position without looking at the sun or the cleft. However, sunset occurred 4–6 minutes after the warnings given by the petroglyphs, and the viewer still needed to observe the sun during the last few minutes before the moment of sunset.

Figure 28. Skyline V as seen through the cleft between Rocks 2 and 3 by an observer standing on the west side of the heelstone with the minimum possible line of sight height of 148 cm. See text. Photographed on Kodak Plus-X film, no filter.

Table 5. Observed Times of Upper Limb Sunset at Counsel Rocks As Viewed from the Heelstone[a]

Date	Time (PST)	Remarks
2006		
Dec. 8	$13^h43^m00^s$	Observation point 12 cm south of standard position at the heelstone.
9[b]	13^h42^m	
10[b]	13^h42^m	In clouds; sunset time uncertain, sunset point outside the V.
11[b]	13^h42^m	Sunset point inside the V.
12[b]	13^h42^m	
15	$13^h44^m00^s$	Sun set between $13^h44^m00^s$ and $13^h44^m30^s$.
17	$13^h45^m20^s$	
18[b]	13^h47^m	In clouds; sunset time uncertain.
19	$13^h46^m38^s$	In clouds.
Dec. 20	$13^h46^m50^s$	
2007		
Dec. 9	$13^h42^m30^s$	Sunset point well outside the V.
10	$13^h42^m00^s$	Sunset point *just* inside the V.
11	$13^h42^m18^s$	Sunset point well inside the V.
12	$13^h42^m35^s$	
13	$13^h42^m53^s$	
14	$13^h42^m58^s$	
15	$13^h44^m13^s$	
16	$13^h44^m46^s$	
17	$13^h45^m34^s$	
18	$13^h45^m42^s$	
19	$13^h46^m14^s$	
20	$13^h46^m59^s$	
21	$13^h47^m36^s$	
22	$13^h48^m45^s$	
23[b]	13^h49^m	
Dec. 24	$13^h49^m10^s$	
2008		
Dec. 20	$13^h47^m22^s$	Observed through cirrus clouds. Sunset between $13^h47^m08^s$ and $13^h47^m37^s$.
Dec. 21	$13^h47^m20^s$	

[a] Observer's eye point 163 cm. above ground, except 2008 Dec 21 when eye point was 148 cm. above ground.

[b] Time uncertain.

The easiest way to do this would appear to have been through the use of a pinhole mask. Observing the sun through a pinhole, the intensity of the solar radiation reaching the eye is reduced, avoiding the temporary blindness caused by viewing the solar disk directly. If the pinhole is too small, *i.e.*, with a diameter $\lesssim$ 0.20 mm, the details of the skyline and the edge of the solar disk become blurred owing to the effects of diffraction. Made too large, temporary blindness still occurs. The optimum pinhole diameter appears to be about 0.30 mm. With this diameter, the amount of blurring due to diffraction is not large enough to be a problem. The full sun is still blindingly bright, so that the details—or even the presence—of the skyline can not be detected. However, the solar intensity is now low enough that it does not produce the temporary blindness caused by viewing the sun directly. As the solar disk begins to be occulted by the skyline, the intensity is still further reduced, so that just before and at the moment of sunset, both the solar limb and the adjoining skyline are clearly visible, even if the observer has been looking at the sun through the pinhole continuously for the preceding several minutes. Masks with pinholes of the requisite size are easily prepared by making holes in a leaf with a readily available Cholla cactus thorn. A dark brown dead leaf works best, but even a green leaf will serve.

At the winter solstice, the sun now sets in the bottom of the V, as discussed above. However, in the past the solstice sunset point lay some distance to the south, owing to the change in the obliquity of the ecliptic with time, as discussed above. Thus, in former times there were *two* significant events preceding the winter solstice:

(1) The entrance of the sunset point into the V.

(2) The setting of the sun in the bottom of the V.

Based on observations in 2006 and 2007 (with the normal viewing height of 163 cm), the sun sets out of the V when $\delta_\odot = -22^\circ\,57'\!.5$, and *just* inside the V when $\delta_\odot = -23^\circ\,01'\!.3$. $\delta_{\odot_{c_1}}$, the first critical value of $\delta_\odot$—when the sun first sets within the V—lies somewhere between these two values. Consequently, in the discussion which follows, two values of $\delta_{\odot_{c_1}}$ will be considered. First, $\delta_{\odot_{c_1}} = -22^\circ\,59'\!.4$, being the average of the two values given above, and second $\delta_{\odot_{c_1}} = -23^\circ\,01'\!.3$ as the limiting case: the most southerly possible value of $\delta_{\odot_{c_1}}$.

Assuming that the sun now sets exactly at the bottom of the V at the winter solstice when the line of sight from the heelstone has its minimum value of 148 cm, the solar declination for this second critical alignment is $\delta_{\odot_{c_2}} = -23^\circ\,26'\!.4$, this being the average of the solar declinations at the winter solstices in 2006 and 2007.

These two critical values of $\delta_\odot$, $\delta_{\odot_{c_1}}$ and $\delta_{\odot_{c_2}}$, serve to define the following intervals of time:

(1) N_1: the number of days that the sun sets within the skyline V from its first appearance in the V up to and including the day

when it sets at the bottom of the V (the base of the right-hand vertical cliff).

(2) N_2: the number of days following the day that the sun sets at the bottom of the V up to and including the day of the winter solstice.

(3) N_3: the total number of days that the sun sets within the V up to and including the day of the winter solstice ($N_3 = N_1 + N_2$).

(4) N_4: the total number of days that the sun sets within the skyline V ($N_4 = 2N_3 - 1$).

These numbers can be calculated directly from the variation of the obliquity with time (see previous section and Appendix 2) or, with somewhat greater accuracy, using the Jet Propulsion Laboratory (JPL) Ephemeris Program (Giorgini et al. 1996), which includes the effect of the change with time in the eccentricity and the longitude of perihelion of the earth's orbit. Values of N_1–N_4, based on the JPL Ephemeris, are listed in Tables 6 and 7 for 500-year epochs between 1,000 B.C. and A.D. 2000. These numbers assume that the observer's line of sight above ground level at the heelstone was 163 cm for observations of the entry of the sunset point into the V, and 148 cm for observations of sunset at the bottom of the V, and have been calculated in two different ways: First, the dates and times in the epoch years at which $\delta_\odot = \delta_{\odot_{c_1}}$, $\delta_{\odot_{c_2}}$, and $-\epsilon$ (its value at the winter solstice) were calculated for the two values of $\delta_{\odot_{c_1}}$ given above yielding the values of N_1–N_4 listed in Table 6. Secondly, the values of $\delta_\odot$ at the moment of Counsel Rocks sunset were found for a number of days before, at, and after the winter solstice. From these, the numbers of days when, at local sunset,

$$\delta_{\odot_{c_1}} \geqslant \delta_\odot \geqslant \delta_{\odot_{c_2}} \qquad (N_1)$$
$$\delta_{\odot_{c_2}} \geqslant \delta_\odot \geqslant -\epsilon \qquad (N_2)$$
$$\delta_{\odot_{c_1}} \geqslant \delta_\odot \geqslant -\epsilon \qquad (N_3)$$

were then read off. This was done for the epoch year and the three following years, to take account of the shift in the sunset point along the skyline due to the leap year effect (deriving from the fact that the year does not consist of an integral number of days). The resulting four whole day numbers were then averaged to give the values listed in Table 7. This second method has the effect of more closely reproducing the values of N_1–N_4 that would have been recorded by the observers at the various epochs.

In addition to the zigzag and inverted V, Figures 20–22 show that the western tunnel of Rock 3 contains a long series of connected petroglyphs. This series would appear to be a depiction of the sunset events leading up to the winter solstice, and a record of the numerical values of N_1 and N_2 at the time that the petroglyphs were inscribed. These petroglyphs run from west to east along the northern end of the tunnel floor, then turn south and descend into a cupule. They

Table 6. Time Intervals (Days) for Sunsets Within Winter Solstice Skyline V,[a] Calculated for Critical Solar Declinations in the Epoch Year

Epoch[b]	$\delta_{\odot_{c_1}} = -22° 59'.4$				$\delta_{\odot_{c_1}} = -23° 01'.3$			
Year	N_1	N_2	N_3	N_4	N_1	N_2	N_3	N_4
−1,000	5.7	9.7	15.4	30.0	5.5	9.7	15.2	29.4
− 500	6.0	8.9	14.9	28.9	5.7	8.9	14.6	28.3
+ 01	6.4	8.0	14.4	27.7	6.0	8.0	14.0	27.1
500	6.8	7.0	13.8	26.6	6.4	7.0	13.4	26.0
1000	7.4	5.8	13.2	25.3	7.0	5.8	12.8	24.7
1500	8.4	4.1	12.5	24.0	8.0	4.1	12.1	23.2
1750	9.2	2.9	12.1	23.2	8.8	2.9	11.7	22.4
+ 2000	11.7	0.0	11.7	22.5	11.3	0.0	11.3	21.7

[a] Calculated from JPL Ephemeris (Giorgini et al. 1966). Intervals are:
N_1: Number of days sun set within V up to and including sunset at the bottom of the V.
N_2: Number of days following sunset at the bottom of the V up to and including the day of the winter solstice.
N_3: Number of days sun set within the V up to and including the day of the winter solstice ($N_3 = N_1 + N_2$).
N_4: Total number of days sun set within the V (Note that $N_4 = 2\,N_3 - 1$, but values given were taken directly from the Ephemeris).
[b] B.C. epochs negative; A.D. epochs positive.

then continue southwards along the eastern edge of the tunnel floor—where the tunnel opens out into the main cavity in Rock 3—ending with a double-headed arrow at the southern end of the tunnel floor. Photographs of the petroglyphs in the series at the north end of the tunnel floor are reproduced in Figures 29–31, and of those at the south end in Figures 32–35. Like the zigzag pattern and inverted V, these petroglyphs were formed by pecking and are, for the most part, deeply engraved into the rock surface. Unlike the zigzag and inverted V, which have line widths of about 10 mm, the lines of the connected petroglyphs are generally quite broad, being typically 15–20 mm, and in one case 25 mm, in width, and with rather ill-defined edges.

As first noted by Rafter (1985), the floor of the west tunnel has been worn smooth, polished and darkened, apparently by contact with human skin over a long period of time. This alteration of the rock surface can be seen in Figures 20, 21, 25, 26, 29–31, and 34. Like those of the zigzag and inverted V, the lines of the connected petroglyphs—with a few exceptions discussed below—show the

Figure 29. Petroglyphs on the floor of the west tunnel in Rock 3 along its northern side. View from main cavity in Rock 3. Enlargement of right-hand photograph in Figure 21 panorama, with eastern edge of sun ray along L7. See text. Photographed on Kodak Plus-X film, no filter, illuminated by flash unit to right of camera. Distance from cupule to L7 = 42.0 cm.

Figure 30. Petroglyphs along northern side of west tunnel floor in Rock 3. Looking northwest from main cavity. Photographed on Kodak Plus-X film, no filter. Illuminated by flash unit to right of camera. Distance from cupule to L7 = 42.0 cm.

Figure 31. Close-up view of petroglyphs along eastern part of north side of west tunnel floor in Rock 3. Photographed on Fuji Provia 100F film. Illuminated by natural light. Scale bar = 10 cm.

Table 7. Time Intervals (Days) for Sunsets Within Winter Solstice Skyline V,[a] Day Count Seen by Counsel Rock Observers[b]

Epoch[c]	$\delta_{\odot c_1} = -22^\circ\, 59\rlap{.}'4$				$\delta_{\odot c_1} = -23^\circ\, 01\rlap{.}'3$			
Year	N_1	N_2	N_3	N_4	N_1	N_2	N_3	N_4
−1,000	5.5	9.8	15.2	29.2	5.0	9.8	14.8	28.8
− 500	5.8	8.6	14.4	27.5	5.5	8.6	14.1	27.2
+ 01	6.0	7.8	13.8	26.8	5.8	7.8	13.6	26.2
500	6.5	6.9	13.4	25.8	6.2	6.9	13.1	25.2
1000	7.0	5.6	12.6	24.2	6.8	5.6	12.4	24.0
1500	8.2	3.8	12.0	23.0	7.8	3.8	11.6	22.5
1750	9.0	2.8	11.8	22.2	8.5	2.8	11.3	21.8
+ 2000	11.5	0.0	11.5	21.5	11.2	0.0	11.2	21.0

[a] Calculated from JPL Ephemeris (Giorgini et al. 1966). Intervals are:
N_1: Number of days sun set within V up to and including sunset at the bottom of the V.
N_2: Number of days following sunset at the bottom of the V up to and including the day of the winter solstice. In this table, N_2 was found from $N_2 = 1/2\,(\Sigma - 1)$, where Σ is the total whole number of days that the sun set in or south of the bottom of the V.
N_3: Number of days sun set within the V up to and including the day of the winter solstice ($N_3 = N_1 + N_2$).
N_4: Total number of days sun set within the V (Note that $N_4 = 2\,N_3 - 1$, but values given were taken directly from the Ephemeris).

[b] Values given are the averages of the whole-day counts for the epoch year and the following three years, to allow for the four-year shift in the sunset point due to the non-integral number of days in the year.

[c] B.C. epochs negative; A.D. epochs positive.

same smoothing and darkening as the adjacent tunnel floor. Thus all of these petroglyphs predate the prolonged period of use which produced the alteration of the tunnel floor, and are, in consequence, very old.

At the southern end of the tunnel floor, the glyphs show evidence of having been constructed at different times, and/or having been subsequently reworked. The double headed arrow at the extreme southern end of the petroglyph panel has a rougher surface and lesser patination or darkening than the glyphs to its north. This appearance could indicate that the arrow was created later than the other markings, but it could also be the result of the repecking of a pre-existing pattern. The shaft of the arrow is, as can be seen in Figures 22, 32, and 34, separated by a gap, 20 mm in length, and is offset laterally from, the long north–south line of the panel which ends immediately to its north. These facts suggest that the arrow was constructed at a different, and most probably later, date than the adjoining petroglyphs.

Certain other features appear, from their degree of surface roughness and patination, to have been repecked, probably at about the same time as the inscription or repecking of the arrow. These include: the southern end of the north–south line, the shallow deviation of this line connecting it to the south end of the loop on the west side of the north–south line, and the southern 5 cm of the loop itself.

The north–south line extends 115 mm south from the last of the short perpendicular lines on the east side of that line. From 40 mm to 115 mm south of the perpendicular line, the north–south line has a rougher surface and less patination than it does to the north of this section. Thus, this portion of the line, including its eastward deviation, was either added or repecked at a later date. The depth of the north–south line is greater between 40 mm and 80 mm south of the perpendicular line, which might indicate that it originally extended 80 mm south of the perpendicular line, and that the last 40 mm of this original line were repecked when the southern extension was added.

The photographs reproduced in Figures 34 and 35 show that the west-side loop has also been reworked. The loop has two southern ends, one joining the north–south line at the north end of the deviation, and the other at its southern end. The southernmost 70 mm of the loop—measured northward from the point where it joins the south end of the deviation—has a roughness and patination like that of the double arrow, the deviation, and the southern 75 mm of the north–south line. Northward, the patination or discoloration is similar to that of the smoothed and darkened petroglyphs of the panel. However, the peck marks in this portion of the loop are more distinct than in the older portions of the north–south line and the short perpendicular lines that connect to it. With proper (low angle) illumination, as in Figures 34 and 35, these peck marks can be traced from the loop into the perpendicular line to which it connects, and then down that line to the north–south line, and across the bottom of this line to its eastern side. The loop, then, may have been engraved, and was clearly reworked to some extent at different times, after the north–south perpendicular lines were inscribed.

Figure 32. Petroglyphs along southern part of rim of west tunnel in Rock 3. See Figure 22. Photographed on Kodak Plus-X film, no filter. Illuminated by flash unit to left of camera. Distance from tip of double arrow to northernmost count line = 60.5 cm.

Also reworked are the two northernmost of the set of short lines at right angles to the north–south line on its western side. As can be seen in Figures 32 and 33, these two lines each consist of an ancient broad, smoothed and discolored feature, in the center of which a deeper, narrow and only slightly less patinated line has been cut. These additions and/or modifications demonstrate that the petroglyphs were being used in some way over a very extended period of time.

The glyphs along the north side of the tunnel floor consist of a series of five north–south lines joining or crossing an east–west connecting line, plus a sixth line at the western end of the series which does not connect to this line. Lines 4 and 6 are also crossed by a second shallower east–west line, shown in Figures 22, 29–31. Close visual inspection shows that this line crosses the bottoms of lines 4 and 6, and was clearly added at a later date. Line number one, the easternmost of these north–south lines, is exceptionally broad and deep (25 mm in width) and descends into a carefully made conical cupule having a depth of 35 mm and a width at its top of 60 mm. These markings would appear to depict the interval N_1: the descent of the sunset point along the right-hand side of the V (the vertical cliff) to its bottom, the bottom of the V being represented by the cupule.[8] The five count lines enumerate the days that the sun set within the V at successively lower points along its right-hand side, and the connection of the easternmost line to the cupule indicates that the sun set at the bottom of the V on the sixth day, so that $N_1 = 6$. As Figure 22 shows, the direction of this set of five lines mirrors the direction of motion of the sunset point as it descends the northern side of the V.

Note that the value of N_1 is not entirely certain from the panel. Clearly, N_1 was at least six. But, is the westernmost (sixth) north–south line also a count line, and if so, what is the meaning of its different position within the panel? Since this line does not reach up to the east–west connecting line, it may be unrelated to the N_1 day count. On the other hand, if it is a count line, it might have been intended to indicate that $N_1 = 6$ to $N_1 = 7$, or a change from $N_1 = 6$ to this number. Also, plotting the position of the solar disk in Figure 27, it appears that lowering the observer's line of sight at the heelstone from the normal height of 163 cm to the minimum height of 148 cm would have caused the sunset point to enter the V approximately one day earlier than when this event was observed along the 163 cm line of sight. This westernmost line may thus have been placed in the panel *below* the level of the other count lines to indicate that this is the value of N_1 if the *lower* line of sight is used.

Similarly, the position of the cupule in the panel may indicate that the lower sight line was used to observe the sunset at the bottom of the V: the cupule appears to be a man-made feature. Thus, its location in the panel was specifically chosen by the engraver. The cupule could, then, have been located at the east end of the line connecting the N_1 count lines. Instead, it is, like the westernmost count line, placed *below* the count and connecting lines, possibly to indicate that the sunset at the bottom of the V (and perhaps the sunset on the day preceding

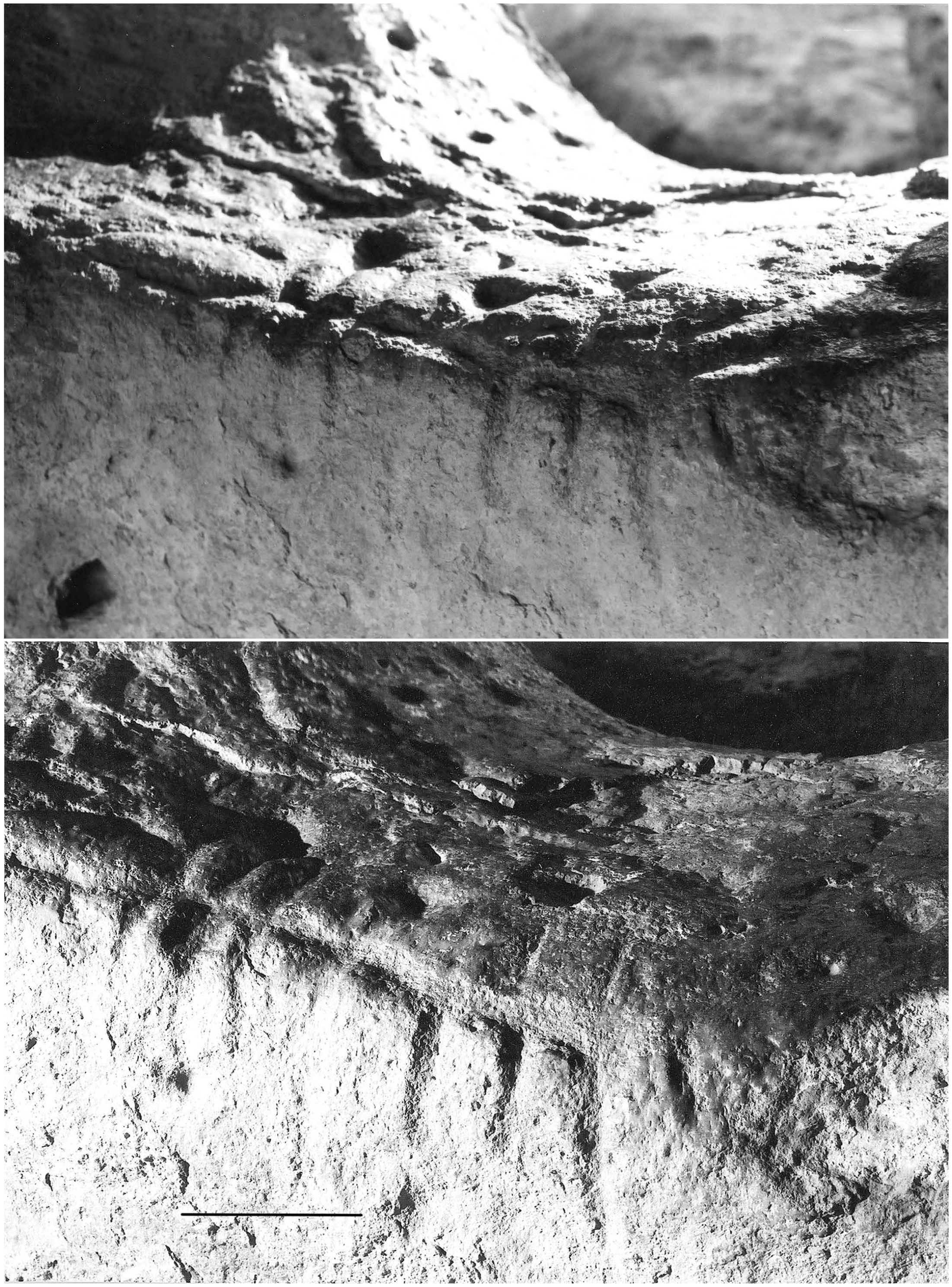

Figure 33. Close-up views of the count lines in Figure 32. Photographed on Kodak Plus-X film, no filter. Top: Illuminated by daylight entering west end of west tunnel. Bottom: Illuminated by flash unit located to left of camera. Scale bar = 10 cm.

Figure 34. Close-up view of double arrow and loop at south end of petroglyphs shown in Figure 32. Photographed on Kodak Plus-X film, no filter. Illuminated by flash unit located to right of camera. Distance from tip of arrow shaft to last (east side) count line = 29.5 cm.

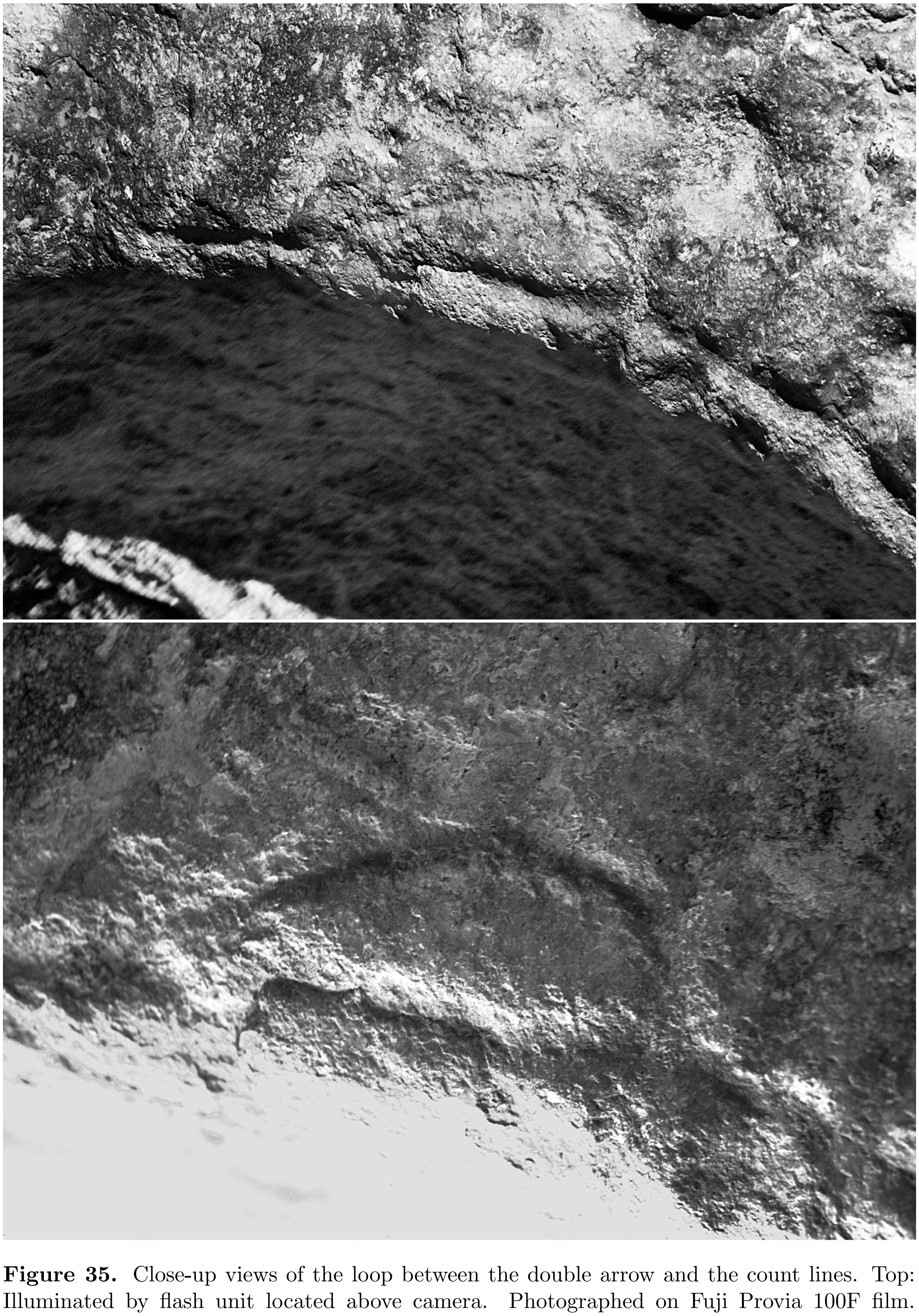

Figure 35. Close-up views of the loop between the double arrow and the count lines. Top: Illuminated by flash unit located above camera. Photographed on Fuji Provia 100F film. Bottom: Illuminated by flash unit located below camera. Photographed on Kodak Plus-X film, no filter. Length of loop = 16.5 cm.

that sunset, since the count line for that sunset descends to the cupule) was to be observed using the lower line of sight.

After reaching the bottom of the V, the motion of the sunset point along the skyline changed from east–west to north–south. The petroglyph line extending southward from the cupule to the double arrow may have been intended to depict this motion, from the bottom of the V southward along the skyline to its location at the winter solstice. The number of days required for the sunset point to move southward to the solstice position (N_2) is then indicated by the eight short lines attached at right angles to the eastern side of the connecting line, the day of the solstice being indicated by the last (eighth) line.

Having arrived at the winter solstice, the sunset point then changed direction and moved northward, as shown by the loop on the west side of the connecting line, which leads from the southern end of that line back to the southernmost of the seven west-side short, perpendicular lines. The west-side lines then give the number of days that it took the sunset point to return to the bottom of the V (the cupule), arriving there on the eighth day after the day of the solstice.

As we have seen, the sunset at the bottom of the V was almost certainly observed along the lower (minimum) line of sight. This would have been true both as the sunset point moved southward before the winter solstice and again as it moved northward after the solstice, in order to accurately determine the value of N_2. Sunset points south of the bottom of the V would not necessarily have to have been observed along this sight line, but it might have been used for ceremonial reasons. That the N_2 sunsets (between the bottom of the V and the solstice) were observed along the lower sight line is possibly suggested by the panel: southward of the cupule, the connecting line of the N_2-related counts originates at, and continues level with, the cupule, rather than passing above it, as does the north-side N_1-count connecting line.

After arriving back at the bottom of the V, the sun then once more set for another five days along the northern side of the V. On the sixth day, the sun set well to the north of the V, beginning its northward march along the western skyline.

A pictograph located within the east-facing cavity of Rafter's (1985) Rock 2 may be another representation of the day count for the interval between sunset at the bottom of the V and the winter solstice. The cavity containing this pictograph is visible in Figure 17. The pictograph itself is not clearly visible in this figure, but is situated about two thirds of the way to the top, and just slightly to the left of center, of the cavity. The pictograph, shown in Figure 36, is executed in black pigment, and is evidently quite old, being much more faded than other nearby pictographs with the same pigmentation. The pictograph, which measures 19 cm in overall length, consists of two parallel rows of eight markings, followed, at the right-hand end, by a single mark placed beyond and midway between the two rows. The leftmost symbols in both rows are larger and darker than the others, and are more nearly circular, having heights roughly equal to their widths. The

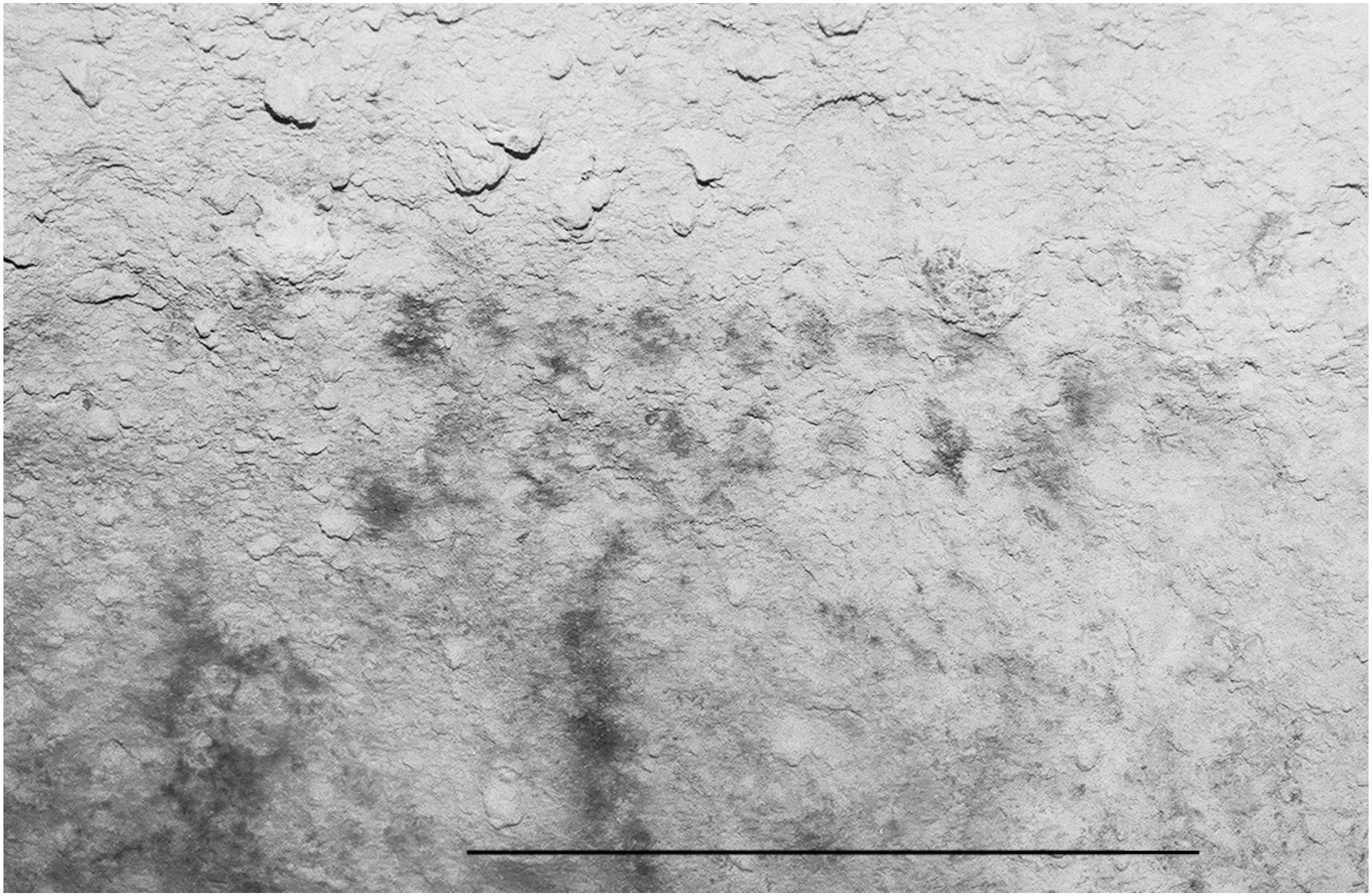

Figure 36. Pictograph in Rock 2 cavity. Photographed on Kodak Plus-X film, through 25A red filter. Illuminated by flash unit mounted on camera. Scale bar = 20 cm.

other symbols have the appearance of very short line segments, with heights of about twice their widths. In this pictograph, the sunset in the bottom of the V might be represented by the larger, left-hand symbols (replacing the cupule of the petroglyph panel), and the sunset at the winter solstice by the single right-hand symbol. The seven smaller marks in each row would then mark the intervening days between these events, one set counting the number of days as the sunset point approaches the winter solstice, and the other days during its return to the bottom of the V.

Referring to Tables 6 and 7, we see that, in fact, when $N_1 = 6^{\mathrm{d}}$, N_2 can equal 8^{d}, as indicated by the petroglyph panel. This fact lends credence to the foregoing interpretation of the west tunnel petroglyph panel and, in addition, provides a rough indication of the time period in which it was inscribed. From Table 6, we find that, to the nearest day, the interval in which $N_1 = 6$ while $N_2 = 8$ extends from about 250 B.C.–A.D. 50 if $\delta_{\odot_{c_1}} = -23^\circ\, 59\overset{\prime}{.}4$, or from about 250 B.C.–A.D. 250 if $\delta_{\odot_{c_1}} = -23^\circ\, 01\overset{\prime}{.}3$. Using the whole-day counts as seen by the Counsel Rock observers, given in Table 7, this interval becomes 400 B.C.–A.D. 150 for both values of $\delta_{\odot_{c_1}}$. These numbers thus suggest that the petroglyphs were initially inscribed sometime between 400 B.C. and A.D. 250. The paths of the center of the solar disk in A.D. 01, based on the values of $\delta_{\odot}$ calculated from the JPL Ephemeris, are indicated by the left-hand set of tic marks labeled "0" in Figure 27, and show that the sun then set at the bottom of the V $N_2 = 8^{\mathrm{d}}$ before the winter solstice when observed from the "minimum" position, and that the sunset point entered the V $N_3 = 13^{\mathrm{d}}$ before the winter solstice.

If initially $N_2 = 8^{\mathrm{d}}$, then as time went on, that count decreased to $N_2 = 7\,{}^1\!/\!{}_2{}^{\mathrm{d}}$, having this value from about A.D. 150–350 (Table 6) or A.D. 60–270 (Table 7). At this point, the south-end count lines could still be used to determine the date of the solstice by re-defining them to refer only to the southward motion of the sunset point prior to the date of the solstice, and taking that interval to be between the two numbers, $N_2 = 8^{\mathrm{d}}$ and $N_2 = 7^{\mathrm{d}}$, given by the two sets of petroglyph lines. The double arrow might have been added at this time to indicate that both sets of count lines now refer to the time taken by the sunset to progress from the bottom of the V to the solstice, rather than to the entire length of time that the sun sets south of the bottom of the V. After A.D. 270 or 350, the count decreased to $N_2 = 7^{\mathrm{d}}$, at which time only the count of seven could be used.

That the critical count, N_2, was observed to decrease from $N_2 = 8^{\mathrm{d}}$ to $N_2 = 7^{\mathrm{d}}$ is also suggested by the well-preserved pictograph on the ceiling of the large cavity in Rock 3, shown in Figure 37. This pictograph, carefully executed in black pigment, and apparently having originally a red background, is set into a natural recess in the ceiling, and consists of seven count lines that cross over and then descend from a connecting bar. By the time that $N_2 = 7^{\mathrm{d}}$, the observers would clearly have realized that N_2 was—for whatever reason—changing with time. There was, in consequence, little point in carving this number in stone

Figure 37. Pictograph on ceiling of main cavity in Rock 3. Photographed on Kodak Plus-X film, no filter. Illuminated by flash unit mounted on camera. Scale bar = 20 cm.

again, particularly as a set of seven count lines already existed. Thus, recording the number in a pictograph which was not only easier to make and to erase, but which could be located well away from the old, no longer useful count lines to avoid confusion, might have seemed preferable.[9]

Of course, ϵ continued to decrease with the passage of time, and further adjustments of the counting marks would have been required. Yet, none are seen. The more rapidly changing interval, N_2, would have to have been changed to $N_2 = 6^d$ by around A.D. 670 (Table 7) or 720 (Table 6). However, no petroglyph or pictograph counts with $N_2 < 7^d$ are to be found, suggesting that by about A.D. 700, the site was no longer being used to mark the date of the winter solstice.

It appears, from the summer solstice-related pictographs at Shelter Rock (see previous section), and the "mid-season" petroglyph at Counsel Rocks discussed in the fifth section, that the site was again occupied beginning around A.D. 1450, or perhaps slightly earlier. By this time, the winter solstice sunset day counts would have been: $N_1 \simeq 8^d$, and $N_2 \simeq 4^d$, as shown by the values listed in Tables 6 and 7. Yet, no such petroglyph or pictograph counts are found. The explanation is probably that by this time, accurate determination of the critical intervals, N_1 and N_2, from observations of the date of sunset at the bottom of the V, had become too difficult owing to the small daily motion of the sun in declination and along the skyline. The daily motion of the sun in declination at the time when it set at the bottom of the V was $\Delta\delta_\odot = 03\overset{\prime}{.}8$/day in A.D. 01 and $03\overset{\prime}{.}2$/day in A.D. 500, but by A.D. 1500 was only $\Delta\delta_\odot = 02\overset{\prime}{.}0$/day. Plotting the daily motions of the solar disk in Figure 27, it can be seen that in A.D. 01, that motion was sufficient to clearly indicate the day of sunset at the bottom of the V. This was probably still the case in A.D. 500, although by this time the observations were becoming more difficult owing to the smaller daily motion. However, by A.D. 1500, the sunset point reached the bottom of the V only four days before the winter solstice, and $\delta_\odot$ then differed from its value at the solstice ($\delta_\odot = -\epsilon$) by only $\Delta\delta_\odot = 0^\circ\,04\overset{\prime}{.}0$. Figure 27 shows that as a result, the uncertainty in determining the date when the sunset point reached the bottom of the V was at least one day, and possibly more. The sunset point then appeared to remain at the bottom of the V until the date of the solstice. Consequently, observing the sun setting in the bottom of the V no longer provided an accurate means of determining the date of the winter solstice. The uncertainty in determining that date was now likely of the order of several days, which would probably have seemed unacceptably large to the Counsel Rocks observers, given their flair for precision—as revealed in the various sections of this paper.

On the other hand, the date when the sunset point entered the V was still well defined, so that the solstice date could be accurately determined from N_4, the total number of days that the sun set within and south of the V. The number of days that the sun sets in the V up to and including the day of the solstice, N_3, is then given by $N_3 = 1/2\ (N_4 + 1)$. As shown by Tables 6 and 7, N_3 had the added advantage of changing more slowly with time than N_2.

Knowing by now that N_3 changed with time, the observers would likely have recorded it in pictographs, rather than petroglyphs, as discussed above. And indeed, we find within the western tunnel of Rock 3, above the opening to the west side of the Rock, two sets of pictograph lines. These lines are (just) visible in Figure 20, and are shown in greater detail in Figures 38a and 38b. A third set of marks to the left of the upper pictograph, visible in Figures 20 and 38a, b, appears to be a natural feature resulting from irregularities in the rock surface. The pictograph lines were painted with black pigment and would appear to be count lines. However, they differ from the other counts in having no connecting bar across the top. They are also much less carefully drawn, the upper right pictograph being the most irregular. In some instances, the painter formed the line with, apparently, a single brush stroke, hitting only the higher points on the rock surface and leaving the depressions unpainted. Owing to this style of painting and to the uneven and deteriorating nature of the rock surface, clearly visible in the figures, the number of lines in the sets is somewhat difficult to determine. Based on visual inspection and analysis of photographs taken with different types of film, filter, and angles of illumination, the upper right-hand set appears to consist of 11 lines, while the lower set has 12 lines. Table 7 shows that, to the nearest day—as seen by the Counsel Rocks observers, $N_3 = 12$ from about A.D. 1100–2000 if $\delta_{\odot_{c_1}} = -22^\circ\, 59'.4$, or from about A.D. 930–1550 if $\delta_{\odot_{c_1}} = -23^\circ\, 01'.3$.

Given the uncertainties in the precise value of $\delta_{\odot_{c_1}}$ and the observer's line of sight, these dates are reasonably consistent with those of the (second) period of occupation inferred in the previous section. These sets of lines may therefore be the observers' notations of N_3, and indicate that it was indeed this interval that was now being used to determine the date of the solstice. Note that the lower set of lines with $N_3 = 12$ is centered over the exit hole of the Rock 3 western tunnel in what would appear to be the prime location for a sunset-related count. It is also the more carefully drawn of the two sets, having straighter and more regularly spaced lines. Thus, this set of lines may be the older of the two, having been painted while N_3 was still closer to 12 than 11, and later replaced by the upper right-hand set as N_3 became closer to 11. The fact that the right-hand set is less carefully drawn perhaps also reflects the observers' feeling that since N_3 was clearly not constant, and now required yet another revision, it was not worth the effort to construct a neat and tidy, high-quality pictograph to record that number. It is also to be noted that, though more crudely drawn, this pictograph has longer, broader, and more widely spaced lines than the lower set of 12 lines. This might have been done to make the upper right-hand set the more visible of the two, and/or to indicate that this was now the one to be used.

As discussed above, all of the values of N_1–N_4 in Tables 6 and 7 assume that the observer's line of sight had a height above ground level at the heelstone of 163 cm for observations of the entrance of the sunset point into the V, and 148 cm for observations of sunsets near the bottom of the V. If a height of 148 cm was used

Figure 38a. Pictographs above the western opening of west tunnel in Rock 3, photographed on Kodak Plus-X film through 25A red filter. Illuminated by flash unit mounted on camera. Upper-right pictograph centered. The lower pictograph appears to the left of center at the bottom of the figure. Scale bar = 20 cm.

Figure 38b. Pictographs above the western opening of west tunnel in Rock 3, photographed on Kodak Plus-X film through 25A red filter. Illuminated by flash unit mounted on camera. Lower pictograph centered. Pictograph is located directly above western opening of the west tunnel, visible in this figure. Upper-right pictograph is at top right of figure. Scale bar = 20 cm.

for *all* of the observations, measurements in Figure 27 indicate that N_1 and N_3 would then be increased by approximately one day, and N_4 by approximately two days, compared to their numbers in Tables 6 and 7. In this case, $N_3 \simeq 12^{\mathrm{d}}\!.2$–$12^{\mathrm{d}}\!.5$ in A.D. 2000 and $\simeq 12^{\mathrm{d}}\!.6$–$13^{\mathrm{d}}\!.0$ in A.D. 1500. Thus, the fact that the west-tunnel pictographs consist of only 12 and 11 lines would indicate that in A.D. 1500, at least, the normal 163 cm line of sight, rather than the minimum 148 cm sight line was indeed being used to observe the entry of the sunset point into the skyline V.

So, now the sun sets at the bottom of the V on the date of the winter solstice. However, ϵ is still decreasing, and soon the solstice sunset point will lie along the north side of the V, and by about A.D. 5580 will no longer set in the V at all. After that, just as with the summer solstice sunrise at Shelter Rock, the sun will not set in the V again for another 20,000 years.[10]

That the petroglyphs and pictographs inside Rock 3 do relate to the winter solstice is further affirmed by the lone petroglyph on the exterior of this rock. That petroglyph, located on the southeast corner of Rock 3, at the entrance of the cleft between Rocks 2 and 3, is shown in Rafter (1991:Fig. 1), and in Figure 39, which reproduces two photographs of the symbol taken from viewing points southeast of Rock 3. As these figures show, the symbol consists of a solidly pecked circle connected by a straight line to a larger open circle located below or, as viewed in the lower photograph in Figure 39, slightly to the left of the upper circle. While at first glance these two features appear perfectly circular, careful measurement of their dimensions on the rock surface reveals that they are in fact slightly elliptical, with major (horizontal, H) and minor (vertical, V) axes of

$$H_u = 10 \text{ cm and } V_u = 9 \text{ cm}$$

for the upper, (u), solidly pecked symbol, and

$$H_{l_i} = 11 \text{ cm}, \; H_{l_o} = 17 \text{ cm}, \; V_{l_i} = 9 \text{ cm}, \; V_{l_o} = 15 \text{ cm}$$

for the inner (i) and outer (o) axes of the lower (l) open circle.

As can be seen in Figures 17 and 39, there are, within the cleft between Rocks 2 and 3, two rocks adjacent to the petroglyph and lying against the northern base of Rock 2. For an observer seated on these rocks, the petroglyph is located at about a forearm's length from the viewer and is seen by the viewer at angles below the horizontal of $h \simeq -40°$ at the top to $h \simeq -60°$ at the bottom of the glyph. The rock surface slopes upward at an angle of $h = 50°$ above the horizontal, so that, seated on the rocks—the engraver's seat—the viewer is looking nearly perpendicular to the rock surface in the vertical direction. However, horizontally the viewer's line of sight is at an angle of about 30° to the left (west) of the perpendicular to the rock surface, so that $i = 60°$. Under these conditions, a symbol which appears circular to the viewer will, as discussed in the previous section, actually be, on the rock surface, an ellipse with major and minor axes a and b respectively, such that $b/a \simeq \sin 60° = 0.87$. This number is in reasonable

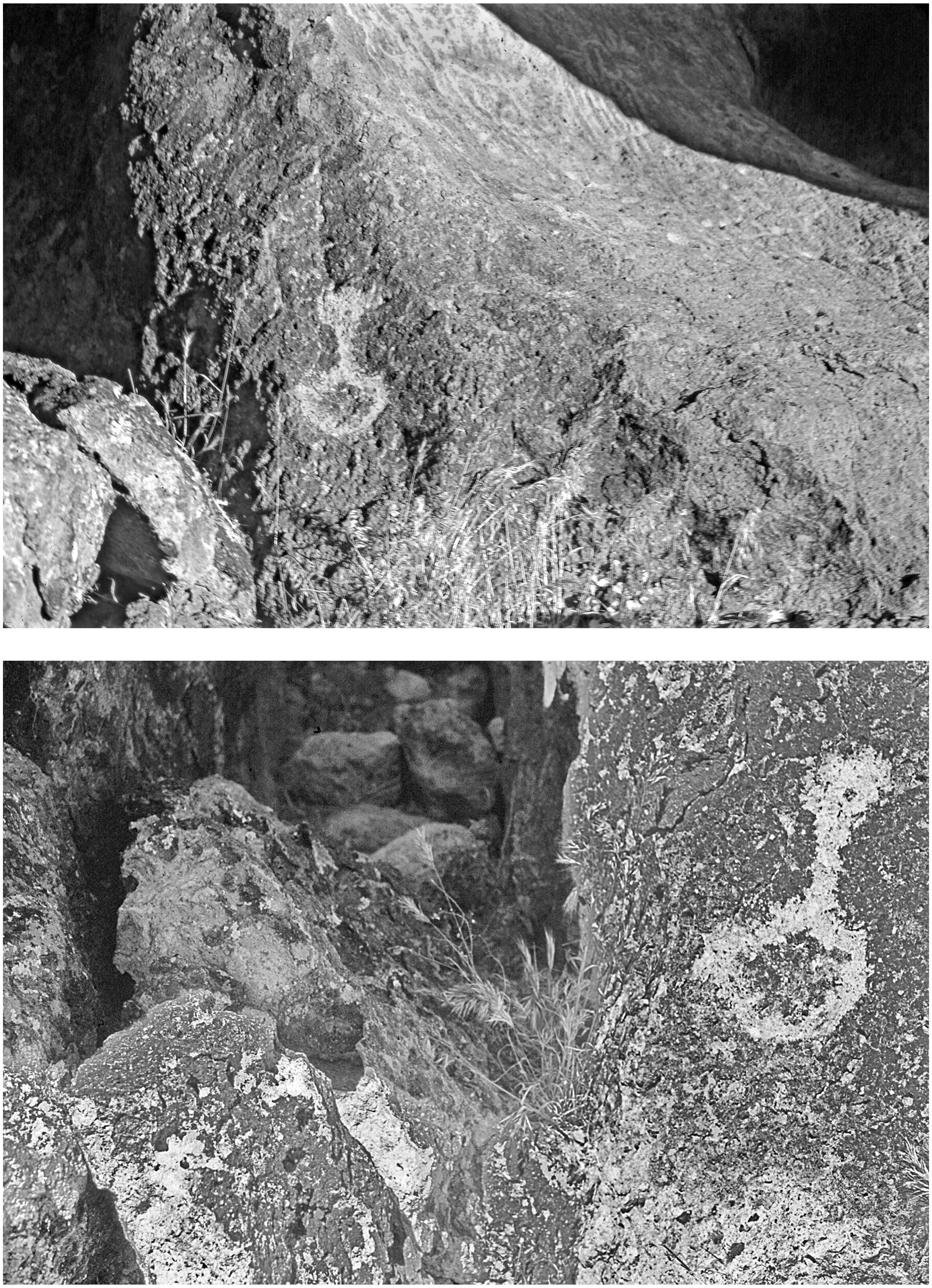

Figure 39. Petroglyph on southeast exterior of Rock 3. Top: Looking northwest to southeast side of Rock 3. Floor of main cavity in Rock 3 at top right. Engraver's seat was on rock at bottom left of figure. See text. Photographed on Kodak Kodachrome 64 film. Bottom: Looking west into cleft between Rocks 2 and 3. Engraver's seat is rock in left foreground. See text. Photographed on Fuji Provia 100F film.

agreement with the ratios of the measured values of the major and minor axes of the petroglyph circles given above. And, when photographed from this viewing position, seated on the engraver's seat, the outlines of the two circles in the petroglyph do appear almost perfectly circular. This is illustrated in Figure 40, which reproduces a photograph taken from this seated position.

In the previous section we have seen that the pictograph makers at Shelter Rock made circles that appeared round to the painter but were elliptical on the rock surface owing to the painter's angle of view. In the fifth section we shall see that this was also done with another petroglyph at Counsel Rocks. It seems certain, therefore, that the Rock 3 petroglyph was also inscribed by a person sitting on the engraver's seat and creating what appeared to him to be two perfectly circular symbols. Knowing that the engraver was seated at this particular point while creating the petroglyph is important because in order to understand its meaning, we must sit where the engraver sat and see the petroglyph in the way that he saw it when he was inscribing it. Seen from this vantage point, the message of the petroglyph now suddenly becomes clear.

Figure 40 shows that, as seen by the engraver, the two circles were not aligned vertically, but were instead arranged so that the solidly pecked circle is at the upper left of the open circle. According to Martineau (1973:39, 40) a symbol at the upper left precedes one at the lower right. Also, as discussed earlier in Section 2, a solidly pecked feature indicates "darkness" or "difficulty," while an open symbol indicates "light" or "no difficulty" (Martineau 1973:49). Read in this way, a dark circle precedes and is connected to a light circle, conveying the idea of going from darkness and difficulty to light and no difficulty. In addition, the upper solidly pecked circle is only a little more than half the diameter of the lower open circle. Returning to Martineau (1973:52, 54, 56, 57) a progression from smaller to larger symbols signifies something coming closer. Thus, using Martineau as a guide, these petroglyphs clearly describe the circumstances of a winter solstice, when the direction of motion of the sunset point along the skyline reverses. No longer is the sun becoming darker (shorter, colder, and more difficult days) and more distant (moving farther south), but is now starting to become brighter (longer, warmer, and more agreeable days) as it moves north (closer). These same concepts were used at Shelter Rock in connection with the summer solstice, as discussed in the previous section.

Finally, note that the line joining the solidly pecked and the open circles is not uniform in width over its entire length. It is broadest at the point where it joins the upper left, solidly pecked symbol, and then decreases to 0.60 ± 0.07 of that initial width at the midpoint of its length. It then maintains this new width onwards to its lower end at the open circle. As discussed in Section 2, broad lines indicate darkness and/or difficulty, while narrow lines indicate light and/or no difficulty. Thus, the line was engraved with decreasing width to further convey the idea of going from darkness and difficulty to light and no difficulty. (A second example of a connecting line which varies in width over its length is found at site

Figure 40. Close-up view of petroglyph on southeast exterior of Rock 3, as seen from the engraver's seat. Edges of figure indicate vertical direction. Photographed on Kodak Elite Chrome 100 Film. Overall length of petroglyph = 35.0 cm.

MFM, discussed in Part 2, Section 2, where that line is used to describe a trail which is at first good, but then becomes difficult.)

The two circles may represent the sun, although they lack the rays usually present in sun symbols. Or, they may simply be a convenient way of representing the more general and more abstract concepts of darkness and light, difficulty and lack of difficulty, and of the transition from something going farther away to something coming closer. In either case, the engraver would appear to be telling us that Rock 3 (and perhaps also the cleft between Rocks 2 and 3, in the entrance of which the petroglyph is located) is dedicated to the timing and, most likely, celebration, of the winter solstice.

This petroglyph shows only a small degree of patination, probably indicating that it was created during the second period of occupation of the site, which, as we have seen, appears to have begun around A.D. 1450.

Another interesting feature of Rock 3, noted by Trupe et al (1988:168–169), is a small hole located in the east wall of the tunnel, partly visible at the left-hand side of Figure 19, which leads downward at an angle of $h \simeq -50°$ from the main cavity to the north side of the Rock. The floor of this tunnel, like that of the west tunnel, has been smoothed and darkened by people passing (probably sliding down) through the tunnel. Here, however, these alterations are less pronounced than in the western tunnel, indicating less frequent use, and/or use over a shorter period of time, than in that tunnel. Unlike the main cavity and west tunnel, the north tunnel contains no pictographs and only one petroglyph. This petroglyph, shown in Figure 41, consists of a single vertical line, 25 cm long and 10–15 mm wide; its lower end is 59 cm above ground level. According to Martineau (1973:17, 18) this type of symbol is a locator, directing the viewer's attention to something at which the line is pointing. Here, the vertical line points to the aforementioned hole in the wall of the tunnel, situated directly above the pointer at a height of 130 cm above the ground. This hole, shown in Figures 41 and 42, has an oval aperture of 8 x 11 cm, and leads through to the east side of Rock 3. Located at shoulder height, it is of a length such that if one inserts his right arm into the hole, his hand emerges on the east side of the Rock, at a height of 120 cm above the ground level. That this was, in fact, done—and done repeatedly—is suggested by the fact that the interior of the hole shows the same type and degree of surface darkening and polish as does the floor of the west tunnel, and a lesser degree of darkening extends downward from the hole, where the side of the person's chest pressed against the tunnel wall. Whether or not this practice was in some way related to the observance of the winter solstice remains unknown.

However, the existence of several highly-patinated petroglyph lines and curves, located on that exterior portion of Rock 3 visible in the extreme upper left-hand corner of Figure 41, may indicate that ceremonial use of the arm hole is very ancient, dating from the earliest recorded period of site occupation.

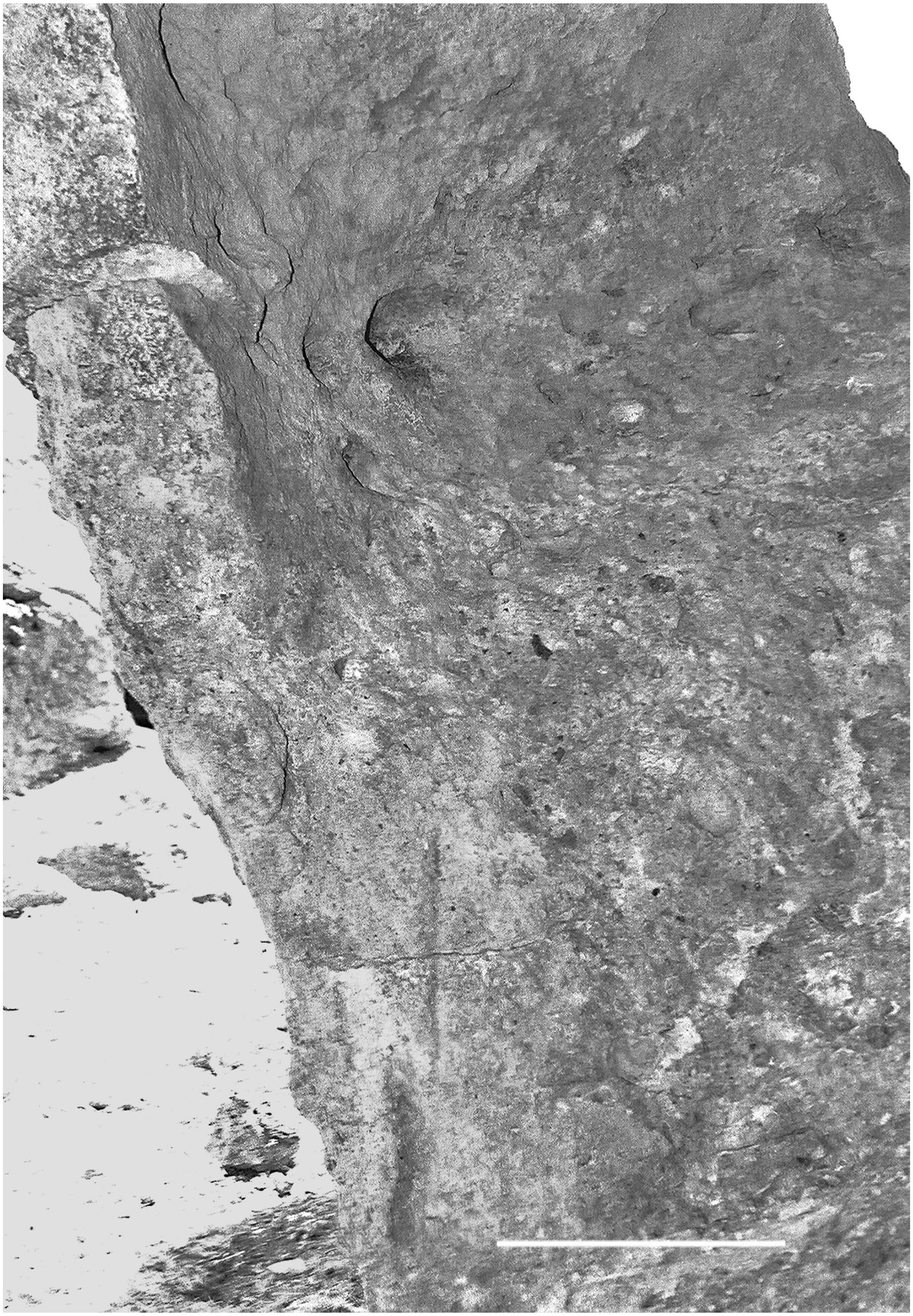

Figure 41. North side of Rock 3, showing interior east wall of north tunnel. Vertical locator petroglyph line points to hole directly above. Opening of north tunnel into main Rock 3 cavity visible at top right of figure. Photographed on Kodak Plus-X film, no filter. Illuminated by natural light. Scale bar = 30 cm.

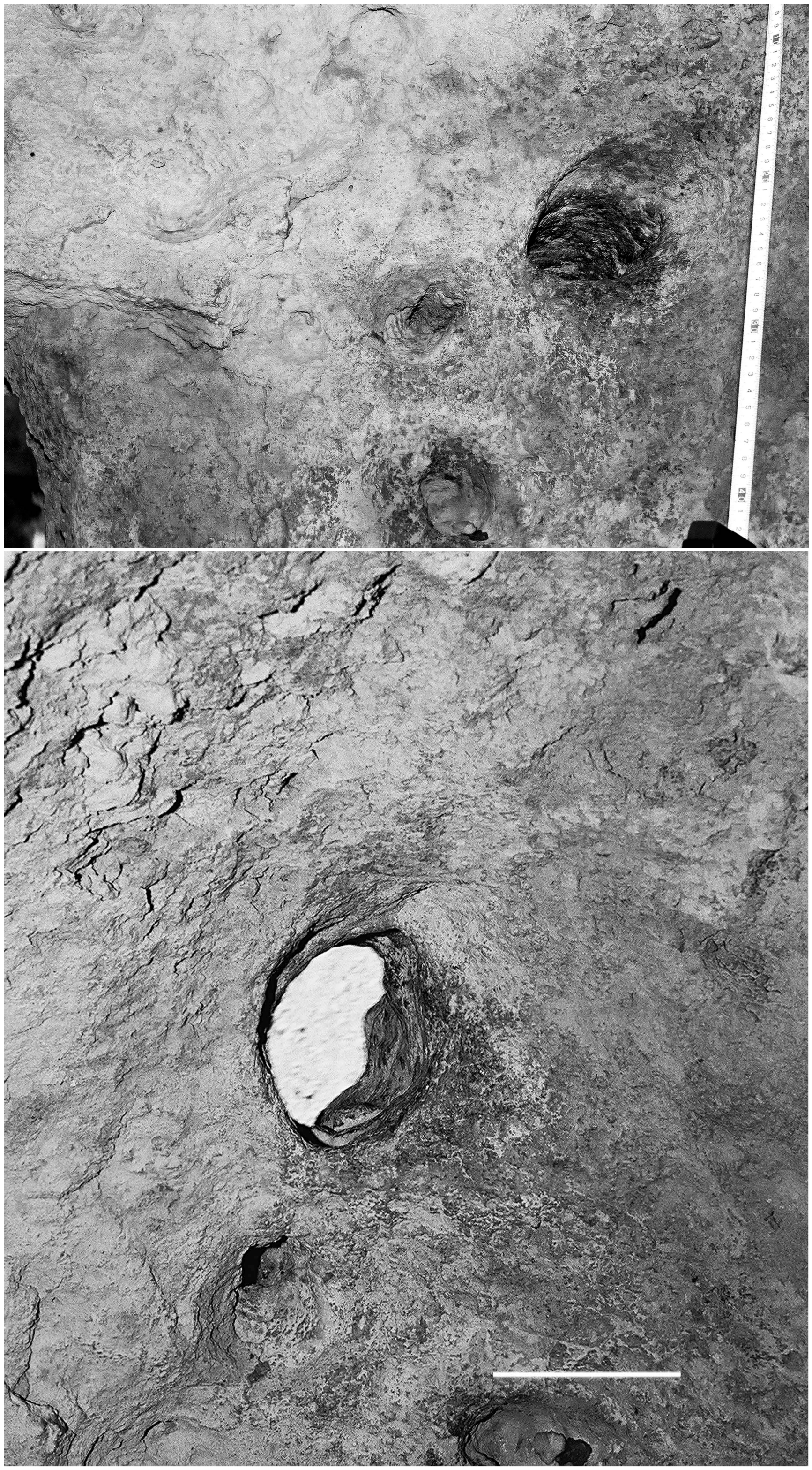

Figure 42. Hole in east wall of north tunnel in Rock 3 indicated by locator petroglyph in Figure 41, photographed on Kodak Plus-X film, no filter. Illuminated by natural light. Top: View from north side of Rock 3. Bottom: Looking down at, and through, hole from main cavity in Rock 3. Scale bar = 10 cm.

4

Observing the Equinox

Rafter (1985, 1987) reports the existence of equinox sunrise alignments at Counsel Rocks (Rafter 1985) and Shelter Rock (Rafter 1987). In both cases, the sun, at the equinoxes, rises at particular, well-defined points on the eastern horizon, as viewed from specific locations at these sites. The difficulty is that there is nothing about these alignments that would tell the observer *a priori* that the sun is in fact at that moment at the equinox. Thus, while these alignments may well have been used to predict or observe the date of the equinox, that date had to have been previously determined by some other means in order for the observer to have been able to select that alignment. The question is, how was this done?

The dates of the solstices can easily be determined with quite high precision by noting the dates on which the sunrise (or sunset) point aligns with a well-defined reference point on the horizon before and after the solstice, as discussed in the previous two sections. The dates of the equinoxes are more difficult to determine. The solstices are marked by an obvious event: the reversal of the direction of motion of the sunrise/sunset point along the horizon; there is no such obvious event at the equinoxes.

One way in which the dates of the equinoxes might he determined is by simply dividing in half the number of days between the solstices. However, this method is not precise owing to the ellipticity of the earth's orbit about the sun. Further, the error introduced by this procedure varies with the epoch of the observations, as discussed in Appendix 2. At present, the date of the vernal equinox derived by dividing in half the interval between the winter and summer solstices is $1^{\mathrm{d}}\!.9$ *later* than the true date. Similarly, the date of the autumnal equinox calculated from the interval between the summer and winter solstices is presently $2^{\mathrm{d}}\!.0$ *earlier* than the actual date. In the past, these differences were smaller, both becoming zero in 4,000 B.C. Since, according to Rafter (1985, 1987), the equinox alignments at Counsel Rocks and Shelter Rock give the correct dates of the equinoxes at the present time, this method could not have been used later than about 2,000 B.C.

The equinox dates might also be determined by marking out on the ground lines of sight to the winter and summer solstice sunrise or sunset points and then bisecting the angle between them. To do this accurately would require an extensive flat area and a horizon altitude of $h = 0^\circ 00'$ between the summer and winter solstice sunrise or sunset points. These conditions do not exist at either Counsel Rocks or Shelter Rock. They do, however, occur (at least approximately) for sunrise observations at Barrier Hill, discussed below, and this type of observation could have been made at that location.

Note that observing the solstice sunrise points does not give precisely the azimuth of the sunrise point when $\delta_\odot = 0^\circ 00'$, except at the equator. This is due to (1) the effect of refraction, (2) the fact that the "sunrise" occurs when the upper limb of the sun, rather than the center of the solar disk, emerges above the horizon, and (3) the change with $\delta_\odot$ in the inclination of the sun's diurnal path at sunrise.

At Barrier Hill, the horizon altitudes at the location of the cairn described below were measured by the writer to be $h = -0^\circ 42'$ at the summer solstice, $h = -0^\circ 47'$ at the equinox, and $h = -0^\circ 57'$ at the winter solstice sunrise points. Extrapolating the values of the refraction (R) published by Young (2004), gives R approximately equal to $1^\circ 54'$ at these altitudes. However, this value is rather uncertain since it depends strongly on the exact atmospheric conditions along the line of sight. Taking $R = 1^\circ 54'$, bisection of the solstice sunrise angle gives a mean azimuth of $A_m = 87^\circ 31'$, corresponding to $\delta_\odot = +0^\circ 20'$. Since the daily motion of the sun (at present) is $\Delta\ \delta_\odot = +23'\!.7$/day at the vernal equinox, the date of that equinox found by this method will be later than the true date by $0^{\rm d}\!.8$.

The easiest and most precise method of determining the equinox dates is by the use of a gnomon. The gnomon has the interesting property that at the equinoxes, when $\delta_\odot = 0^\circ 00'$, the path of the tip of its shadow during the day is a straight line from west to east. This results from the fact that at the equinoxes, the sun lies in the plane of the great circle of the celestial equator, while the shadow of the tip of the gnomon lies not only in the plane of the celestial equator, but also in the plane of the great circle of the horizon, and the intersection of two great circles is a straight line. When $\delta_\odot \neq 0^\circ 00'$, the path of the shadow tip is curved. In northern latitudes, the curve is convex toward the south when $\delta_\odot < 0^\circ 00'$ and towards the north when $\delta_\odot > 0^\circ 00'$. In fact, $\delta_\odot \equiv 0^\circ 00'$ only instantaneously; as indicated above, the change in $\delta_\odot$, at the vernal equinox, is presently $\Delta\ \delta_\odot = +23'\!.7$/day. Thus if, for example, the vernal equinox occurred at local noon, the path would be slightly "S" shaped during the day, being convex toward the south in the morning and toward the north in the afternoon. Between sunrise and sunset $\Delta\ \delta_\odot = +11'\!.8$ and the azimuth of the sunrise–sunset line will exceed 90° by $\Delta\ A = 05'\!.9$ (sec ϕ), where ϕ is the latitude of the observer. Since the gnomon observations would probably be made within a few hours of local noon, $\Delta\ A$ will be considerably smaller than for the complete sunrise–sunset line, so that the effect of the daily motion will not produce a very significant error.

Gnomon observations are generally considered to be rather inaccurate owing to the uncertainty introduced by the diffuseness of the shadow of the tip of the gnomon, resulting from the appreciable angular diameter (32′) of the solar disk. However, if the tip of the gnomon is replaced by a sphere, a significant improvement in accuracy results. The edges of the elliptical shadow of the sphere are indeed diffuse. But, that diffuseness is the same in all directions, and the eye is capable of estimating the center of a symmetric diffuse light or shadow figure with quite high precision. As a test, a gnomon having a height of 36.5 mm to the top of the sphere and with a sphere diameter of 2.0 mm was used to determine the time of the equinox from measurements of its shadow path on several days near the vernal equinox. In one year, observations were obtained during the two days before and three days following the day of the equinox (which was cloudy). The curvature of the shadow path of the sphere was determined by measuring the sagittae of the curves at noon from chords intersecting the curves at points about $4^{\rm h}\!.3$ before and after the noon point. The least-squares solution of the measures of the sagittae on the different days yielded an observed time of the equinox that was $1^{\rm h}\!.0$ earlier than the true value, and which had a standard deviation of $\sigma = \pm 1^{\rm h}\!.8$. In a second year, observations were obtained on the day before and on five days after the day of the vernal equinox (which was again cloudy!). In this instance, the observed time was $3^{\rm h}\!.8$ earlier than the true time of the equinox and $\sigma = \pm 2^{\rm h}\!.5$. Thus, an error of only one or two tenths of a day is easily achievable using a gnomon. The question is, did the Counsel Rocks observers know about this property of the gnomon? A discovery by Rafter (1985) indicates that they did.

Rafter (1985) describes a cairn located on the top of a plateau or mesa, referred to by him as “Barrier Hill,” southeast of Counsel Rocks. This cairn has unfortunately been disturbed; photographs of the cairn as it exists today are reproduced in Figures 43–50, and 53–56. (All of these photographs were taken on March 23, 2004.)

However, a sketch published by Rafter shows that it originally consisted of a pile of rocks supporting and anchoring a long, protruding wedge-shaped pointer rock. Laird (1984:315), quoting a letter from Rafter, describes this pointer as being “painted.” Rafter (1985) does not mention the pointer being painted, although he describes it as being a “white stone.” It appears from the author’s examination that the “painting” probably referred to the fact that, as shown in Figures 49, 50, 54 and 55, portions of the east and under sides of the pointer are covered with a white deposit like that seen on many of the (volcanic tuff) rocks of the region. These coatings appear to be material leached out of the interior of the rocks and deposited on their surfaces. Spectroscopic analysis of this type of deposit by Professor Eli Silver of the Earth Sciences Department, University of California, Santa Cruz, indicates that this material is the mineral corrensite (E. Silver, personal communication 2012). According to Rafter’s sketch, the pointer had a slight upward curve and was directed upwards at an angle, measured along the mid-line of its side, of $h = 43°$ above the horizontal. According to Rafter, the tip of the pointer had a height of 68.5 cm above the ground level, and the

Figure 43. Cairn on Barrier Hill. General views. Top: Looking approximately southeast. Bottom: Looking approximately north. Photographs taken about $12^{h}\,00^{m}$ PST. (Note that all photographs of the cairn were taken on March 23, 2004.) Length of white wooden tripod legs = 42 cm.

rock pile had a diameter of 76 cm at its base. Figures 43–45, 48, and 54–56 show that the pointer has been uprooted from its original position so that it now points upward at an angle of $h \simeq 60°$, and has been tipped and turned sideways so that its top surface now makes an angle of $h \simeq 30°$ with the horizontal in the direction perpendicular to its length. The scales given by the tape measure included in some of these photographs confirm that the diameter of the rock pile at its base is about 76 cm, as reported by Rafter. However, using the photographs to determine the scale of Rafter's sketch from measures of the diameter of the rock pile and of key features of the pointer stone, it would appear that the top of the rock pile was originally about 39 cm above the slab or about 42 cm above ground level, and that the tip of the pointer was about 45 cm above the slab or 48 cm above ground level. At present, the pointer tip is still about 44 cm above the slab and 47 cm above ground level, the increased inclination of the pointer being offset by its sideways tilt.

According to Rafter (1985), the pointer was directed to a point on the southeast horizon approximately 10° to the west of the observed location of the winter solstice sunrise point. As indicated above, the altitude of the horizon at this point was measured by the writer to be $h = -0° 57'$. Assuming that the refraction at this altitude was $R = 1° 54'$ (based on extrapolation of the values published by Young [2004]), the azimuth of the winter solstice sunrise point when it was observed by Rafter in 1982 was $A = 116° 38'$. Thus the azimuth of the pointer was $A \simeq 127°$.

As noted by Rafter, the cairn is situated some 90 m from the north edge of the plateau. It is thus not visible from Counsel Rocks. Interestingly, however, Rafter found that the cairn lies along an extension of the line of sight from Counsel Rocks to the point where the winter solstice sun first appears above the top of Barrier Hill as viewed from Counsel Rocks. For this reason, Rafter surmised that the cairn had some connection to the winter solstice, although its exact purpose was unclear.

To investigate the purpose of this cairn, we consider first the altitude and azimuth of its pointer. The base slab on which the cairn was constructed was measured by the writer to be inclined slightly upwards towards the southeast at an angle of $h = 5°$ above the horizontal, in agreement with its appearance in Rafter's sketch. Using the inclined slab as the reference, the altitudes of the top, bottom and middle of the outer half of the pointer were measured on Rafter's sketch as follows:

(1) Altitude of the top edge of the pointer: $h = 31°$.

(2) Altitude of the mid-line of the side of the pointer: $h = 43°$.

(3) Altitude of the bottom edge of the pointer: $h = 58°$.

At the equinox, the altitude of the sun, when its azimuth is $A = 127° 00'$, is $h = 40° 39'$. In view of the uncertainties in determining both the altitude and

Figure 44. Barrier Hill Cairn pointer stone viewed perpendicular to its southwest face. Photograph taken about $12^{h}\,00^{m}$ PST.

Figure 45. Pointer stone viewed from the west, showing its southwest and bottom sides. Photograph taken about $12^{h}\,00^{m}$ PST.

azimuth of the pointer, the agreement between the altitude of the sun and of the mid-line of the pointer is quite good. Thus, the altitude and azimuth of the pointer indicate that it was directed to the equinoctial sun at the moment when the sun aligned with the axis of the pointer. Aligned in this way, the axis of the pointer lay in the plane of the great circle of the celestial equator. Consequently, during the day of the equinox, the shadow of each point along that axis fell along the same west-to-east straight line. This alignment suggests that the cairn was designed to be used in connection with observations of the sun at the equinoxes. Note that the alignment of the sun with the mid-line of the pointer rather than with its top or bottom edges is what we might expect if the observer was in fact aligning the pointer to the altitude of the sun. Since the observer could not look directly at the sun, he would most likely adjust the pointer by affixing a short horizontal stick to the tip of the pointer. Waiting until the sun had passed the azimuth of the pointer, he would adjust the altitude of the pointer so that the shadow of the stick bisected the side of the pointer. (It is interesting to note that in fact the altitude of the equinoctial sun was $h = 43^\circ\,00'$ $14^{\mathrm{m}}\!.6$ after it aligned with the axis of the pointer. At that time, a stick projecting 2.0 cm beyond the west side of the pointer at its tip cast a shadow 31 cm in length down the entire length of that side. However, the significance of this fact is difficult to assess owing to the uncertainties in the values of the altitude and azimuth of the pointer, as discussed above.)

To investigate how the cairn might have been used to observe the sun at the equinoxes, a two-dimensional cardboard model was constructed by tracing the outline of the cairn and pointer from Rafter's sketch. This model was then mounted in $A = 127^\circ$ on a leveled board and the nature of its shadow, when illuminated by the sun, was observed. The result was truly remarkable. At the equinox, the rather ungainly looking pointer cast a shadow that was nearly conical and whose axis lay closely along the west-to-east direction of motion of the shadow of the tip of the pointer, during both the morning and the afternoon. This shape, and the orientation of the axis of the cone along the shadow path, was maintained even well away from the equinox. In a test when $\delta_\odot = +18^\circ$, the morning and afternoon shadows were both still nearly conical in shape. In the afternoon, the axis of the cone was still fairly close to the direction of motion of the shadow tip, even though that path was now strongly curved. However, in the morning the axis now deviated from the path direction by an amount that varied with the altitude of the sun, but generally ranged from about 7°–10°, the deviation being smaller at low sun altitudes.

The direction and diurnal motion of the shadow cone are thus totally unlike those of the shadow of a conventional gnomon, which consists of a vertical rod, or of the common sundial, whose gnomon slopes northward. In these cases, the shadow swings around in an arc from (approximately) west to east during the course of the day. Consequently, as discussed above, unless the gnomon is tipped with a sphere, accurate mapping of the path of the shadow of its tip is extremely

Figure 46. Pointer stone viewed from northwest, showing its top and southwest sides. Photograph taken about $12^{h}\,00^{m}$ PST.

Figure 47. Pointer stone, as in Figure 46. Photograph taken about $14^{h}\,00^{m}$ PST. Length of extended scale = 54 cm.

difficult. In the case of the pointer, however, the accuracy in the north–south direction is quite high because the conical shadow is equally diffuse on both its north and south sides and thus, as discussed above, the north–south position of its center can be estimated with considerable precision. The location of the *tip* of the shadow remains, of course, quite uncertain. However, this uncertainty does not significantly affect the accurate plotting of the shadow path. As just discussed, the shadow cone is aligned along that path. Thus, the north–south location of the center of the path is relatively insensitive to the exact point along the axis of the cone at which its center is measured. These observations appear to confirm that the cairn was indeed a gnomon and, moreover, a gnomon that was designed specifically for the purpose of determining the dates of the equinoxes.

Having established the purpose and general behavior of the cairn pointer, more refined three-dimensional cardboard models were constructed, that took account of the width of the pointer. As shown in Figure 46, the top surface of the pointer is rather broad, being approximately 9 cm wide over its entire length. The width of the bottom side of the pointer is likewise about 9 cm over that portion of the stone that was visible when the pointer was mounted in its original position, as can be seen in Figures 48, 49, 50, and 55. However, the models were constructed and tested prior to visiting the cairn site, and the width of the pointer was estimated from Rafter's sketch to be 5 cm rather than 9 cm.

Models were constructed in which the width of the top and the bottom side of the pointer were the same, and in which the width of the bottom side was zero. Models were also constructed with pointer altitudes less and greater than the altitude of the sun when it was in alignment with the pointer. In all of these models, the outlines of the sides of the pointer were traced from Rafter's sketch, and thus corresponded to a pointer tip approximately 42 cm above ground level. Finally, two metal models were constructed in which the top and bottom sides of the pointer again had widths corresponding to 5 cm in the original pointer. The actual widths of these pointers were 5.0 mm, and their heights to the tips of the pointers were 41.5 mm. The first of these models was a simple wedge with straight top and bottom sides. The altitude of the center-line of this model was $h = 42\overset{\circ}{.}5$ and the wedge angle was $31\overset{\circ}{.}0$. The second model basically copied the outline of the cairn pointer in Rafter's sketch, and was used to investigate the effects of small changes in the shape of the pointer on the appearance of its shadow at different times of the day. This was done by modifying the tip and edges of the model with a file while observing the resulting shape of the shadow cone. Slight changes near the tip of the pointer proved to be particularly effective in improving the symmetry of the cone. Ultimately, after these modifications, this model had the following characteristics:

(1) Altitude of:
  a) Top, outer half of pointer: $h = 33°$.
  b) Top, rear half of pointer: $h = 26°$.
  c) Center-line, outer half of pointer: $h = 47°$.

Figure 48. Pointer stone, top surface. Photograph taken about $14^{h}\,00^{m}$ PST.

d) Center-line, rear half of pointer: $h = 40°$.
e) Bottom, outer half of pointer: $h = 61°$.
f) Bottom, rear half of pointer: $h = 53°$.

(2) Pointer tip: rounded, approximately but not precisely semicircular, with radius $r = 2.5$ mm.

(3) Width of top and bottom sides: approximately 5.0 mm, but with slight modifications.

(4) Height to tip of pointer: 41.5 mm.

The behavior of the shadows of these models at the equinox was observed by first calculating for each model the location of its equinoctial shadow path at the cairn site. Next, the model was mounted on a leveled board. This board was then rotated in altitude and azimuth until the shadow of the pointer cast by the sun fell at different points along the calculated path. These observations demonstrated that:

(1) Changing the altitude of the pointer from the altitude of the sun at alignment by only a few degrees causes a perceptible deviation of the axis of the shadow cone from the direction of the shadow path. With $\Delta\ h = \pm 8°$, this deviation was very clearly visible, the tip of the shadow cone pointing north of the shadow path when the pointer altitude was larger, and south of the path when the pointer altitude was smaller, than the altitude of the sun at alignment.

(2) Models with equal top and bottom widths perform slightly better than those with bottom widths of 0 mm. With equal top and bottom widths, the axis of the shadow cone aligns more closely with the direction of the shadow path than when the bottom width is zero, particularly for the morning observations.

(3) Changing the altitude and azimuth of the pointer does not affect the shape or direction of the axis of the shadow cone so long as the axis of the pointer points to the sun when the sun has the same azimuth as the pointer axis, *e.g.*, $h = 53\overset{\circ}{.}0$, $A = 158\overset{\circ}{.}4$. This is what we would expect since, as discussed above, the pointer axis then lies in the plane of the celestial equator.

(4) The shape of the shadow cone is quite sensitive to the shape of the pointer, particularly during the morning hours. Note that, as indicated above, the top (and bottom) widths of these models were estimated from Rafter's sketch. They are, in consequence, too narrow compared to their lengths and vertical dimensions as a result of underestimating the foreshortening in Rafter's illustration. The top widths in these models thus correspond to a

Figure 49. Pointer stone. Top: Looking approximately south, showing top and northeast sides of pointer. Photograph taken about $14^{h}\,00^{m}$ PST. Bottom: Northeast side. Photograph taken about $14^{h}\,50^{m}$ PST.

> width of about 5 cm in the original pointer, whereas subsequent direct measurement shows these widths to be about 9 cm, as illustrated in Figures 46 and 50. More recent tests have been made with models constructed to match the true 9 cm width of the pointer. These tests show that the main effect of increasing the pointer width is to broaden the shadow cone, but without significantly changing the way in which the pointer performs, or the accuracy in determining the date of the equinox that can be achieved through its use.

The cairn pointer appears to have been specifically shaped so as to produce the most nearly symmetric conical shadow possible and the closest possible alignment of that shadow with the equinoctial shadow path, in both the morning and afternoon. That the cairn pointer was very carefully shaped is also suggested by the appearance of the forward half of its top surface. As shown in Figures 46–48, this surface displays numerous small indentations, more or less similar in size, that appear to be tool marks resulting from the sculpting of that surface; this pattern is not seen on the rear half of the pointer stone, or on the surfaces of the other rocks of the cairn.

In order to determine the date of the equinox, the curvature of the shadow path of the cairn pointer had to be measured. To do this, observations at low morning and afternoon sun altitudes were needed, together with observations around local noon, when the sun was on or near the meridian of the site. Since the shadow path lies north of the gnomon in northern latitudes, the base of a south-pointing gnomon will interfere with the noontime observations. The Barrier Hill observers solved this problem by simply turning the gnomon towards the southeast. As near as can be determined using the models constructed to match Rafter's sketch, the gnomon was turned just enough to cause the meridian shadow cone to fall, at the equinoxes, just clear of the base rock pile. Naturally, one loses the shadow in the morning, when the sun aligns with the pointer, but these observations are not needed in order to determine the curvature of the shadow path.

The fact that the azimuth of the pointer lies close to the azimuth of the winter solstice sunrise is thus most likely coincidental. As discussed above, a wide range of azimuths would have served. The only requirements were that the pointer had to point to the altitude of the equinoctial sun when the sun's azimuth equaled that of the pointer, and that the shadow of the pointer at local noon had to be clear of the pile of rocks that anchored and supported the pointer. It is clear that from the standpoint of its use, the pointer had nothing to do with the winter solstice. Furthermore, it seems likely that if the observers had wished to align the pointer axis to the winter solstice sunrise point, either as seen from the cairn site or from Counsel Rocks, they could and would have done so with an error much less than the values of $\Delta A \simeq +10°$ for the sunrise at the cairn site and $\Delta A \simeq -7°$ for the sunrise as seen from Counsel Rocks.

In practice, the observers would probably have measured the curvature of the

Figure 50. Pointer stone, looking northwest, two views showing bottom side, under different angles of illumination. Left: Photograph taken about $12^h\,00^m$ PST. Right: Photograph taken about $14^h\,51^m$ PST.

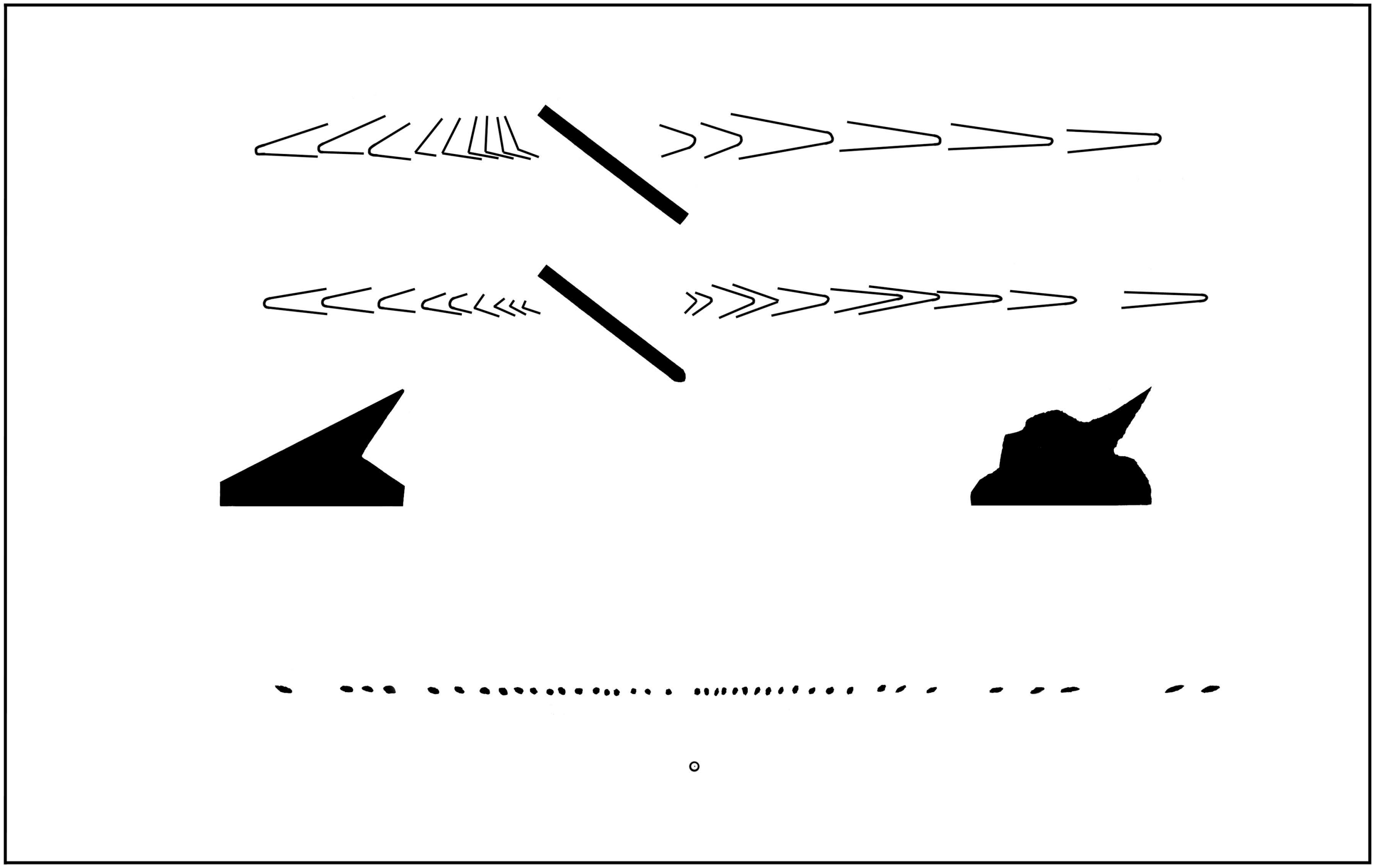

Figure 51. Shadow tracks on the day of the autumnal equinox produced by: Top: Gnomon having wedge shape with straight sides. Middle: Gnomon replicating the Barrier Hill Cairn and its pointer stone. Bottom: Vertical gnomon, tipped with a sphere. Bars show length, width and location of the bases of the wedge and Barrier Hill gnomon models, as well as the shapes of their pointer tips. Profiles of these models are shown in the middle of the figure: wedge model left, Barrier Hill model right. Location of the vertical gnomon is indicated by the circle at the bottom of the figure. See text. The height of the pointer tips of these models was 41.5 mm.

cairn pointer shadow path in the following manner: first, a few observations of the position of the center of the shadow cone were made with low morning sun, marking its progress with small stones or (more likely) pegs driven into the ground. A second set of observations was then made at noon, and a third with low sun in the afternoon. By observing with morning and afternoon sun altitudes of $h_\odot = 12°–14°$, the curvature of the shadow path even one day from the equinox would have been readily detectable by simply sighting along the sets of markers. As discussed above, the height of the tip of the gnomon is stated by Rafter to have been 68.5 cm above ground level. Thus when $h_\odot = 12°–14°$, the tip of the pointer's shadow lay some 3–4 m from the cairn. Rafter's sketch and the present photographs suggest a tip height of around 48 cm, in which case the tip of the shadow would have lain about 2 m from the cairn.

To investigate the accuracy with which the date or time of the equinox could have been determined using the cairn pointer, observations were made with the two metal ("5-cm") models described above together with the vertical, sphere-tipped gnomon discussed earlier. These observations are shown in Figures 51 and 52, which reproduce tracings of the shadows of the three gnomons made on September 23 and 24, 2003, at a latitude differing from that of the cairn by only $\Delta\ \phi = 0°\,04'$. Outlines of the two metal gnomons, to the scale of the shadow tracings, are shown in the centers of the figures, while the widths and positions of the models are shown by the bars. The lengths of the bases of the models match the distance from the tip of the cairn pointer to the rearward end of the rock pile supporting it, in the direction of the pointer axis, as measured on Rafter's sketch. Observations of the shadow of the wedge model are shown at the tops of the figures, with the observations of the shadow of the model of the actual cairn pointer (modified to improve the shadow, as discussed above) just below. Observations of the shadow of the sphere of the vertical gnomon are shown at the bottom of the figures, and the location of this gnomon is indicated by the circle. The observations cover the interval from $06^h\ 40^m$–$16^h\ 30^m$ PST. These figures illustrate the fact, discussed above, that very small changes in the basic wedge shape of the pointer can significantly improve the shape and orientation of its shadow, particularly for the morning observations.

Examination of Figures 51 and 52 shows that on September 23, the day of the equinox (which occurred at $02^h\ 47^m$ PST), the shadow paths of the vertical gnomon and the cairn model are essentially linear, with only a very slight curvature, convex towards the south. One day later, on September 24, the curvature of the paths is already quite evident by simply sighting along the observed path. This result shows that the Barrier Hill cairn could indeed have been used to determine the dates—or in fact, times—of the equinoxes with an error of considerably less than one day: Inspection of these observations, and of the shadow cones of the later "9-cm" models, suggests that the curvature of the path of the cairn-pointer shadow could probably have been determined with nearly the same precision as is attained using the sphere-tipped gnomon which, as we have seen,

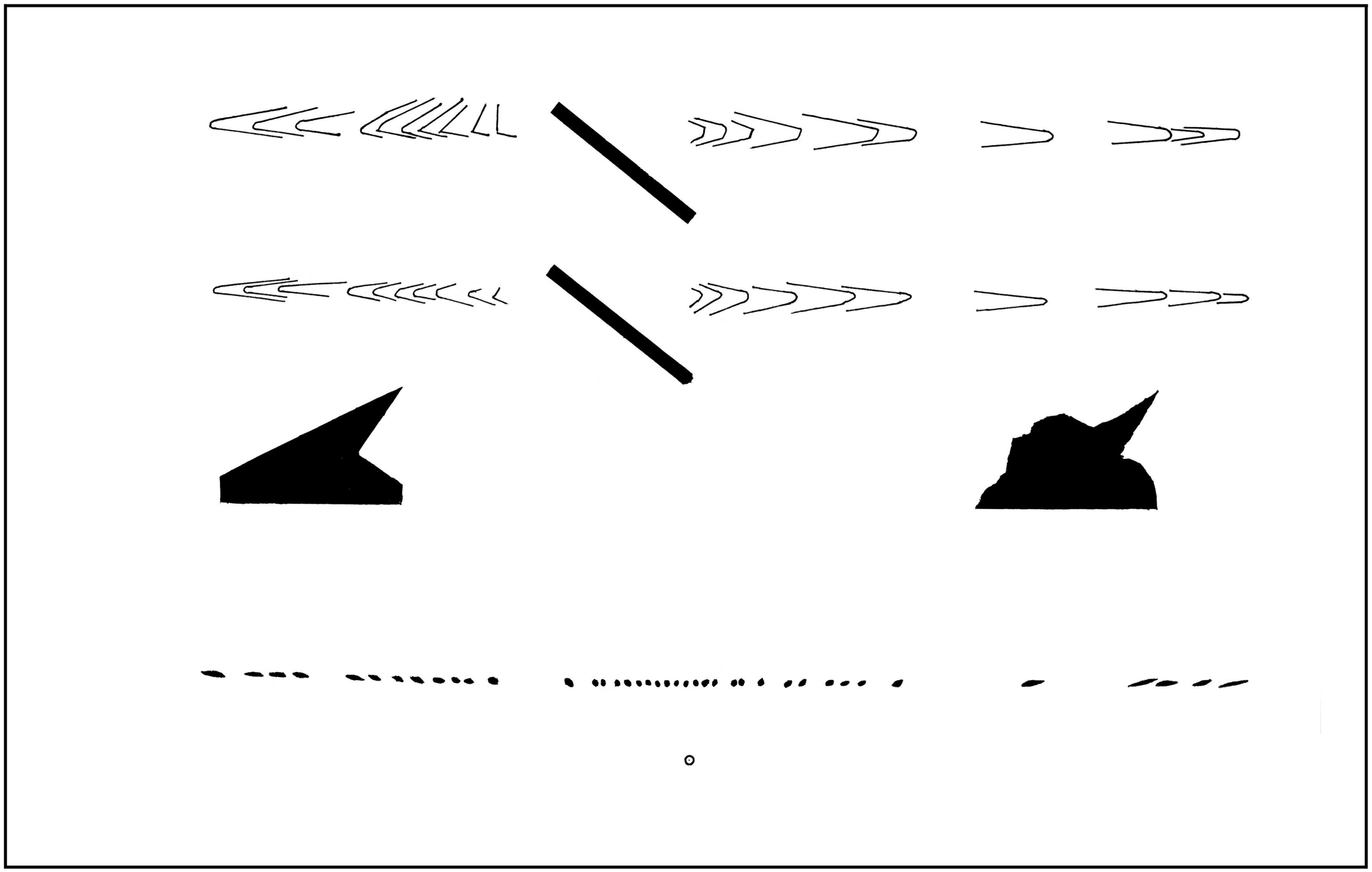

Figure 52. Shadow tracks on the day following the autumnal equinox, produced by the gnomons in Figure 51. Symbols as in Figure 51. Shadow paths are now noticeably curved. See text.

Figure 53. Barrier Hill Cairn, with shadow of pointer stone, looking northeast. Photograph taken about $14^{\mathrm{h}}\,00^{\mathrm{m}}$ PST.

yields an uncertainty in the time of the equinox of $0^{\mathrm{d}}.1$–$0^{\mathrm{d}}.2$.

The change in the curvature of the shadow path between September 23 and 24 can also be detected in the observations made with the straight-sided wedge model. However, the measurement of that curvature is less accurate than with the sphere or the actual cairn pointer, owing to the asymmetric and changing shape of the shadow during the morning hours. Using a straight-sided wedge-shaped pointer, accurate results would only be obtained by restricting the morning observations to very low sun altitudes.

It is interesting to note that even in its present changed position, the cairn pointer still produces a beautifully symmetric, conical shadow during the afternoon at the equinox. This is shown by the photographs reproduced in Figures 53–57, taken on March 23, 2004, one day after the vernal equinox. However, while the shadow cone in Figure 57 appears very similar to those of the model in Figures 51 and 52, that similarity in fact results from the changed position of the pointer and to the fact that the widths of the models were too narrow. Tests with a model of the pointer having a width corresponding to 9 cm show that with the pointer in its original position its shadow is broader than shown in Figures 51, and 53–57, becoming narrower when moved to the present orientation of the pointer stone. Still, the present shadow is similar to that of the pointer in its original position, and enables us to see the shadow essentially as the original observers saw it. And it is indeed an extraordinary, moving, almost eerie experience to see this perfect conical shadow emerge from what appears at first glance to be nothing but a jumbled pile of rocks.

In order to avoid missing the equinox due to clouds, and to be able to predict in advance the exact date of its occurrence, the observers would probably have marked out on the ground the shadow lines for several days around the equinox, leaving the markers in place for use in subsequent years. Accurate observations during a single equinox could have been made using a simple gnomon consisting of a sphere—a round gourd, perhaps—mounted on the top of a wooden stick. However, such a gnomon could not be relied on to give consistent shadow paths from one equinox to the next. In order to lay out shadow lines and re-use them from year to year, it would have been necessary to have a very stable gnomon whose position would not shift over a long period of time. The Barrier Hill gnomon fulfilled that requirement. The cairn pointer was clearly constructed to be extremely stable and thus capable of giving consistent results over an interval of many years.

The reasons for locating the cairn on the top of the Barrier Hill mesa are now clear. First, if one wants to lay out gnomon shadow lines, the site must be flat and have an unobstructed view down to $h \simeq 10°$. Secondly, the site must be located in a place where the gnomon and shadow markers can be set up and left in place without being disturbed by the people living in the vicinity. The Barrier Hill location satisfies both of these requirements: as indicated above, the site is located near the center of the Barrier Hill mesa, well away from, and out of sight

Figure 54. Barrier Hill Cairn, with shadow of pointer stone, looking west. Photograph taken at $14^{h}\,43^{m}$ PST.

Figure 55. Barrier Hill Cairn, with shadow of pointer stone, looking north. Photograph taken about $14^{h}\,46^{m}$ PST.

of, areas of human activity. In addition, it has an unobstructed view down to $h \leqslant 3°$ in all directions.

As we have seen, the cairn itself had nothing to do with the winter solstice; the azimuth of the pointer was chosen simply to permit observation of the pointer shadow at local noon. Yet, as pointed out by Rafter (1985), the cairn *is* situated along the extension of the line of sight from Counsel Rocks to the observed winter solstice sunrise point above Barrier Hill. There are several possible reasons for this alignment:

(1) Coincidence. The choice of location of the cairn was most likely governed by the considerations discussed above. The alignment to the winter solstice sunrise point may then have been merely a happy coincidence.

(2) Ceremonial reasons. Since the cairn is not located *precisely* in the center of the Barrier Hill mesa, its position may have been adjusted slightly to let it lie along the extension of the winter solstice sunrise line for ceremonial reasons. What these reasons might have been is not clear, since the cairn itself was unrelated to the winter solstice.

(3) Direction indicator. Location of the cairn along an extension of the winter solstice sunrise line, engraved along the northeast face of Rock 6, might have served as a means of indicating the direction to the cairn from Counsel Rocks and, possibly, the route to the top of the mesa. The ascent of Barrier Hill is rather difficult owing to the presence of four vertical cliffs that must be surmounted enroute to the top. Following the line of sight from Counsel Rocks to the winter solstice sunrise point does, in fact, bring the climber close to points where these cliffs can be scaled more easily.

(4) Deception. The cairn might have been located along the winter solstice sunrise line in order to conceal its true purpose, making it appear that it was in some way related to observations or observances of the winter solstice (as was assumed by Rafter [1985]), rather than an instrument for the observation and prediction of the equinoxes. Since this device appears to have been unique, its location, purpose, and method of employment may well have been jealously guarded secrets.

As indicated above, the dates of the equinoxes might, in principle, have been determined by bisecting the angle between the summer and winter solstice sunrise points. The Barrier Hill mesa would have seemed to the ancient observers to be an ideal place to carry out such measurements: As pointed out earlier, the site is flat, the level area having a total width of some 300–400 m, so that accurate

Figure 56. Barrier Hill Cairn pointer stone and its shadow, looking south. Photograph taken about $14^{h}\,54^{m}$ PST.

Figure 57. Shadow of pointer stone, looking vertically downward. Photograph taken at $14^{h}\,57^{m}$ PST.

direction lines to the sunrise points could have been easily laid out on the ground. It also has a nearly true horizon from the northeast to southwest (although peaks and mesas rise to $h \simeq 2°$–$3°$ between the southwest and the north). The observers would have been unaware of the (small) error that would result from using this method at that site. However, because of the existence and unique nature of the Barrier Hill cairn pointer, it seems unlikely that the equinox dates were determined in this way. For such observations, only a simple vertical marker stone would have been required, to serve as the reference point from which to make the sunrise sightings. There would have been no need to construct the unique and sophisticated pointer that was placed on the top of Barrier Hill. In addition, as we shall see in the next section, the fact that the correct date of the vernal equinox was used in locating the mid-season petroglyph indicates that bisection of the sunrise angles was *not* used in determining that date.

The age of the Barrier Hill gnomon is uncertain, since the declination of the sun at the equinox does not change with time. However, once again the fact that the correct date of the equinox was used in locating the mid-season petroglyph would indicate that the pointer was in existence when this marker was inscribed.

5

Mid-Season Day at Counsel Rocks

Rafter (1985) has described a petroglyph at Counsel Rocks, circular in shape, positioned so that it marks the dates in the spring and summer when the sun has a declination half way between its value at the equinox ($\delta_\odot = 0^\circ 00'$) and at the summer solstice ($\delta_\odot = +\epsilon$). As Rafter suggests, these dates probably served to mark the observance of "mid-spring" or "mid-summer." These events were very likely similar in purpose to the "mid-quarter" days in prehistoric and medieval times in the British Isles (McCloskey 1989). The mid-quarter days were ceremonial occasions to mark the true beginnings of the seasons, since these lag behind their respective equinoxes and solstices. However, unlike the celebrations at Counsel Rocks, the dates of the mid-quarter days were, apparently, determined from day counts—dividing in half the number of days between the equinoxes and solstices—rather than from the declination of the sun.

Rafter's Rock 4 at Counsel Rocks contains an east-facing cavity with an aperture in the top through which, near midday, a ray of sunlight falls onto the lower portion of the cavity. When $\delta_\odot = +\epsilon/2$, this ray takes the form of a finger or arrow of light, oriented approximately east–west, with its tip at its eastern end. The ray passes through the center of a circle pecked into the surface of the cavity, as shown in Figure 58. A detailed study of this event has yielded the results shown in Figure 59. This figure shows the smoothed outline of the petroglyph on the rock surface. As can be seen, the symbol is not actually circular, but is, in fact, slightly elliptical. This fact shows that the petroglyph was constructed with considerable care. It was pecked into the rock in such a way that, as seen by the engraver or observer, sitting in the only possible location within the cavity, the outline of the symbol appears perfectly circular due to the angle at which the rock surface is viewed. This appearance is shown in the photograph reproduced in Figure 58, which was taken from the observer's position within the cavity. This petroglyph thus resembles two of the pictographs in the Shelter Rock overhang, discussed in the second section, and the petroglyph outside Rock 3 at Counsel

Figure 58. Photograph of sun's ray passing through circular petroglyph in Rock 4 cavity at Counsel Rocks when $\delta_\odot = +11°40.'3$ ($\delta_\odot = +\epsilon/2 - 0°03'$). North at the top, east to the right. View from engraver/observer's position within the cavity. See text. Outer diameter of circle = 7.5 cm.

Rocks discussed in the previous section, that were likewise constructed so as to appear circular to the painter, or engraver. (A further example of this type of construction is provided by the sun symbol at site MFM, described in Part Two of this volume.)

The finger of light, which slowly pierces the circle from west to east, has a width at 2 cm from its eastern tip of about 2 cm. The edges of the finger are rather diffuse, owing to the angular size of the solar disk. However, as discussed in the preceding section, since that diffuseness is the same for both sides of the finger, the position of its center in the north–south direction can be estimated with a precision that, based on repeat visual and photographic measures of the event, is $\sigma = \pm 1.1$ mm for a single measurement or $\sigma = \pm 0.5$ mm for the average of five measures as the finger traverses the circle. Since the observed north–south displacement of the finger (in April) is 11 mm/day (corresponding to $\Delta\delta_\odot = +20'\!.5$/day), these errors amount to $\pm 02'\!.0$ and $\pm 00'\!.9$, respectively, in $\delta_\odot$.

The upper left illustration in Figure 59 shows the change in the present-day position of the center line of the finger at one day intervals from the moment when $\delta_\odot = +\epsilon/2$, while the upper right panel illustrates the maximum variation due to the four-year leap-year cycle. It will be seen that at present, unless one observes when the declination of the sun is almost exactly $\delta_\odot = +\epsilon/2$ at the time that the finger traverses the circle, the center of the finger will be noticeably displaced from the center of the petroglyph. It would appear, therefore, that the observers made observations over a number of years and averaged the results before *very* carefully locating the petroglyph. This is illustrated in Figure 58, which reproduces a photograph taken at $13^h\ 04^m$ PST on April 20, 1998, when $\delta_\odot = +11^\circ\ 40'\!.32$ ($\delta_\odot = +\epsilon/2\ -3'$). In this photograph, the measured center of the finger is, on the rock surface, about 1 mm ($2'$) north of the center of the petroglyph, differing from the calculated displacement by only $1'$, which is equal to the error of measurement for the average of five observations.

If, then, we assume that the intent of the observers was to have the center line of the finger of light pass precisely through the center of the circle when $\delta_\odot = +\epsilon/2$, we can, owing to the precision with which the center line can be located, determine an approximate date for the construction of the petroglyph. Going backwards in time, the obliquity of the ecliptic increases, as detailed in Appendix 2. The location of the center line of the finger for various epochs from A.D. 2000 to 3,000 B.C. is shown in the remaining panels of Figure 59. From the figure, it can be seen that the finger becomes detectably off-center in the petroglyph somewhere between A.D. 1000 and A.D. 2000, suggesting that the petroglyph was constructed within perhaps the last 500 years.

As previously noted, the petroglyphs at Counsel Rocks, including those within the Rock 4 cavity, display a considerable difference in the amount of patination that has occurred since their creation. Some are very heavily patinated, while others appear quite fresh and have sometimes been inscribed over the patinated symbols. The $\delta_\odot = +\epsilon/2$ or "mid-season" petroglyph belongs to this latter class,

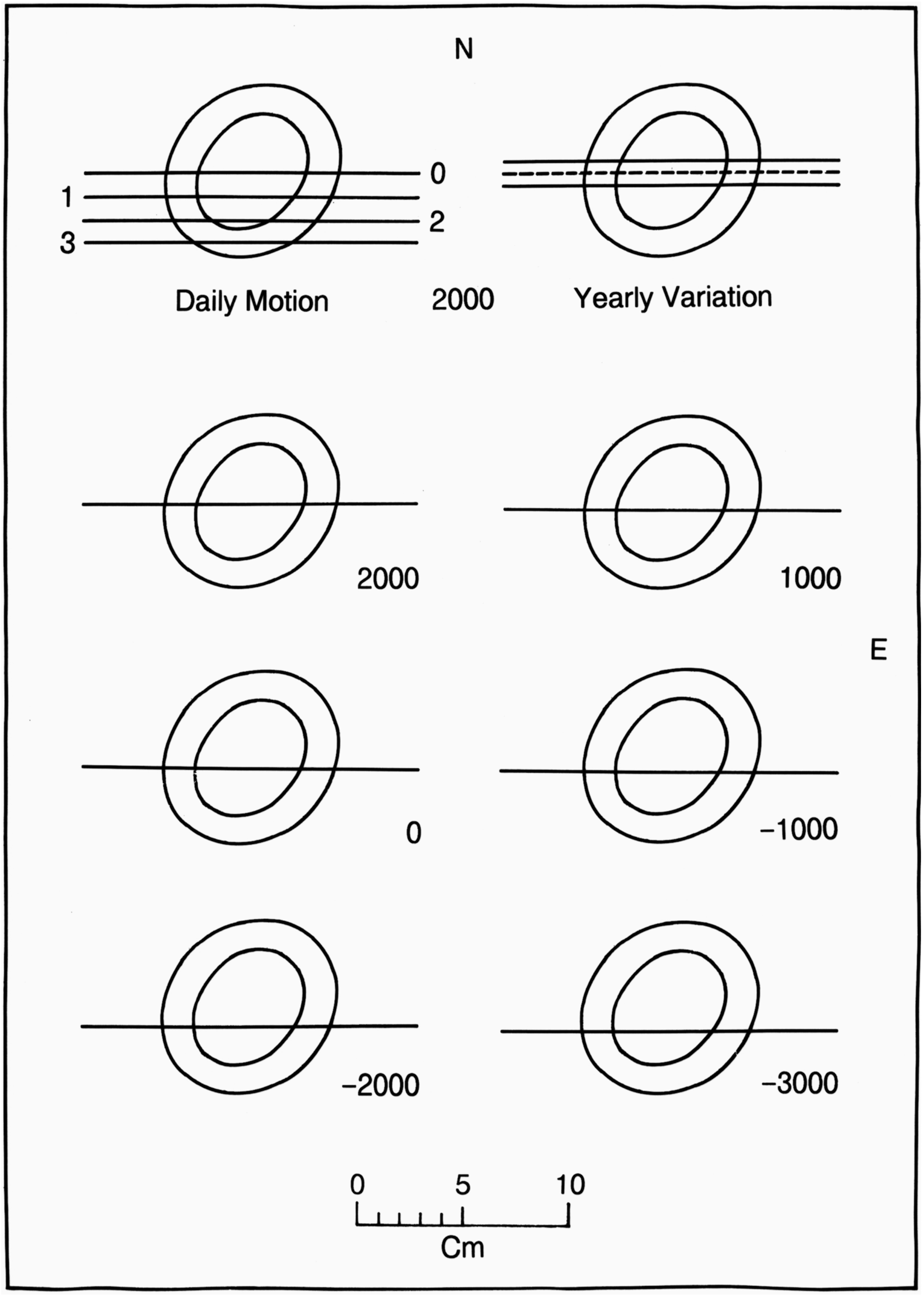

Figure 59. Path of center of sun arrow across Rock 4 petroglyph at Counsel Rocks. Top left, when $\delta_\odot = +\,\epsilon/2$ (day zero) and on the three following days (in April). Top right, variation due to the fractional number of days in the year, A.D. 2000. Remainder of figure shows position of sun arrow at $\delta_\odot = +\,\epsilon/2$ between A.D. 2000 and 3,000 B.C.

providing further support to the conclusion that it is not extremely old.

The mid-season petroglyph, then, is very precisely located so that the ray of sunlight bisects it when the solar declination is exactly $\delta_\odot = +\epsilon/2$. The question is, how were the observers able to determine that location?

Unlike the equinoxes, the dates when $\delta_\odot = +\epsilon/2$ can not be found, even approximately, from day counts. Furthermore, without a knowledge of trigonometry, the observers could not have determined them by the use of a gnomon. The dates could have been determined directly if the ray of light fell on a rock surface which was curved so that it maintained the same distance between the entrance aperture and the rock surface from the equinox to the summer solstice solar ray points. Rafter (1985) states that the sun's ray passes north and south of the mid-season petroglyph at equal distances from it at the equinox and summer solstice. However, observations by the writer at the equinox and summer solstice show that, in fact, the distance from the petroglyph to the path of the summer solstice ray is about twice the distance from the petroglyph to the path of the ray at the equinox. Thus, the dates when $\delta_\odot = +\epsilon/2$ could not have been determined by measurements within the Rock 4 cavity.

Seemingly, then, the only method available to the Counsel Rocks observers would have been that of bisecting the angle between the equinoctial and solsticial sunrise (or sunset) points. This could be done by laying out these directions on the ground. However, in order to obtain an accuracy of a few arc minutes, as is implied by the alignment of the sun's ray with the mid-season petroglyph, a large flat area with a view down to the true horizon from at least the summer solstice to the equinox sunrise (or sunset) points would have been required. These condition do not occur at Counsel Rocks, but do exist, for sunrise observations, at the cairn site on Barrier Hill, as discussed in the previous section. Here, the tip of the pointer rock could have been used as the reference point for laying out lines of sight to the summer and winter solstice and the equinox and mid-season sunrise points. Even in the case of the winter solstice sunrise, the orientation of the pointer to an azimuth some 10° west of the sunrise point would have made it possible to sight along the west side of the pointer from its tip (apparently about 48 cm above the ground) to the sunrise point. The extent of the top of the mesa would have permitted sunrise markers to be placed on the ground up to about 150–200 m from the reference point at the cairn. At that distance, $\Delta A = 0^\circ 01\overset{\prime}{.}0$ corresponds to a lateral shift of 4.4–5.8 cm. Thus, an accuracy of the order of one to a few arc minutes in azimuth would have been readily attainable.

It should be noted, however, that just as bisecting the angle between the summer and winter solstice sunrise points does not give the exact azimuth of the equinox sunrise except at the equator, so too bisecting the angle between the equinox and summer solstice sunrise points does not, except at the equator, give the true azimuth of the mid-season sunrise ($A_{\epsilon/2}$) when $\delta_\odot = +\epsilon/2$. Away from the equator, the azimuth of the bisector, A_m, differs from $A_{\epsilon/2}$ by an amount which increases with increasing latitude, A_m being always $<A_{\epsilon/2}$. Even for the simple

"geometric" case, where sunrise is defined as the moment when the center of the solar disk has an altitude of $h = 0^\circ\,00'$ and there is no refraction, the difference at Barrier Hill amounts to $\Delta\ A = A_m\ - A_{\epsilon/2} = -0^\circ\,10'$, and $\delta_\odot$ corresponding to A_m is $\delta_{\odot\epsilon/2}\ +0^\circ\,06'$. More realistically, if we take sunrise to be the emergence of the upper limb of the sun above the horizon, then if $h = 0^\circ\,00'$ and we assume that the refraction (R) at $h = 0^\circ\,00'$ (the horizontal refraction R_0) is $R_0 = 0^\circ\,44'$ (Young 2004), $\Delta\ A = -0^\circ\,12'$ and the corresponding $\delta_\odot = \delta_{\odot\epsilon/2}\ +0^\circ\,10'$.

At Barrier Hill, the azimuth of the mid-season sunrise point could have been determined in either of two ways:

(1) The Barrier Hill cairn could have been used to determine the date of the equinox and thus the direction of the equinoctial sunrise, and the angle between this point and the summer solstice sunrise point bisected.

(2) The directions to the summer and winter solstice sunrise points could have been observed and the angle between them bisected to give the equinox sunrise point. The angle between the equinox and summer solstice sunrise points could have then been bisected to give the mid-season sunrise point.

Since the cairn existed and was almost certainly used to determine the time of the equinox, it is more likely that the first method would have been used.

Using the cairn, the observers would probably have proceeded as follows:

First, the Barrier Hill gnomon would have been used to determine the date of the equinox. We shall assume that these observations were made only at or near the vernal equinox. This is likely to have been the case since, if the climate was similar to that at the present time, little or no water would have been available in the region at the time of the autumnal equinox, making observations at Barrier Hill difficult, if not impossible. Observations would have been made over a number of years to eliminate the leap year effect, and the corresponding sunrise points noted. Since the gnomon observations were centered on local noon, the average of the sunrise directions would then have given the observers the sunrise point corresponding to the occurrence of the equinox at local noon. The solar declination at sunrise is then, at present, $\delta_\odot = -0^\circ\,06'$, owing to the daily motion of the sun in declination. Assuming that $R = 1^\circ\,54'$, as discussed in the preceding section, the azimuth of the sunrise point is $A_e = 88^\circ\,03'$.

Next, the date of the summer solstice would have been determined, probably from observations at Shelter Rock, and the location of the solstice sunrise point marked. Here, because the sun is nearly stationary in declination for several days, no correction for the leap-year effect or daily motion was needed. At the summer solstice, $\delta_\odot = +23^\circ\,26'\!.3$ (A.D. 2000), and the observed horizon altitude is $h = -0^\circ\,42'$. Assuming that $R = 1^\circ\,54'$, the azimuth of the solstice sunrise point is $A_s = 58^\circ\,34'$.

Bisecting the angle between the equinox and solstice sunrise markers, we obtain the mean azimuth $A_m = 73^\circ\,19'$. At this azimuth the observed horizon altitude is $h = -0^\circ\,05'$, and assuming $R = 0^\circ\,44'$, the solar declination is $\delta_\odot = +12^\circ\,57'$ at sunrise.

If the mid-season sunrise observations were made in April when the sun is moving northward, then $0\overset{d}{.}290$ after sunrise, when the sun's ray traverses the petroglyph circle, the solar declination will have increased to $\delta_\odot = +13^\circ\,03'$. Conversely, if the observations were made in August when the sun is moving southward, the declination ($0\overset{d}{.}286$ after sunrise) would have been $\delta_\odot = +12^\circ\,51'$, while if observations in both April and August were used, the averaged position would correspond to $\delta_\odot = +12^\circ\,57'$. At present $\epsilon/2 = 11^\circ\,43\overset{\prime}{.}1$ (A.D. 2000), thus, this method would locate the mid-season petroglyph too far south on the rock surface by an amount corresponding to $\Delta\,\delta_\odot = -1^\circ\,20'$, $-1^\circ\,08'$, or $-1^\circ\,14'$, respectively, depending on which mid-season observations were utilized. These angles are equal to 43.0, 36.7 and 39.8 mm, respectively, on the rock surface, and are all in excess of the (present) daily motions of $\Delta\,\delta_\odot = +20\overset{\prime}{.}46$/day (in April) and $\Delta\,\delta_\odot = -20\overset{\prime}{.}28$/day (in August).

Let us now suppose that the observers determined the date of mid-season solely from observations of the summer and winter solstice sunrise point directions at Barrier Hill without using the cairn to determine the equinox. In this case, bisecting the angle between the summer and winter solstice points will give an equinox sunrise azimuth of $A_e = 87^\circ\,35'$, corresponding to $\delta_\odot = 0^\circ\,00'$ at sunrise. Bisecting the angle between this point and the summer solstice direction then gives $A_m = 73^\circ\,05'$, so that $\delta_\odot = +13^\circ\,09'$ at sunrise. Thus at midday, $\delta_\odot = +13^\circ\,15'$ in April, $\delta_\odot = +13^\circ\,03'$ in August, or $\delta_\odot = +13^\circ\,09'$ if both April and August observations are combined. These values of $\delta_\odot$ are $12'$ larger than those derived using the cairn observations to locate the equinox sunrise point.

If the observers had used the cairn to determine the direction of the equinox sunrise by combining observations made at both the vernal and autumnal equinoxes, this procedure, averaged over the four year cycle, would have given them the sunrise azimuth when $\delta_\odot = 0^\circ\,00'$ at sunrise, *i.e.*, $A_e = 87^\circ\,56'$, so that $A_m = 73^\circ\,15'$ and $\delta_\odot = +13^\circ\,00'$ at sunrise. Consequently, at midday $\delta_\odot = +13^\circ\,06'$ in April, $\delta_\odot = +12^\circ\,55'$ in August, and $\delta_\odot = +13^\circ\,01'$ if April and August observations were combined.

It is clear that despite the errors introduced by the uncertainties in the values of R, measures of the sunrise angles at Barrier Hill will not give the correct time of mid-season. Therefore, the observers had to have used measurements from some other location in order to have achieved the observed accurate bisection of their mid-season petroglyph by the sun's ray exactly when $\delta_\odot = +\epsilon/2$.

Even for the Counsel Rocks observers who were presumably accustomed to such activity, the ascent of Barrier Hill to the cairn site represented a fair amount of effort and inconvenience. Not only was the ascent strenuous, but in order to observe the sunrise it would probably have been necessary to spend the night at the site, exposed to the cold and wind, to avoid trying to make the climb in the dark. A shelter could, of course, have been constructed, but since the top of the mesa is arid and quite barren, much of the building materials and firewood, as well as all of the food and water would have to have been brought up from the desert floor. Thus, even though the cairn site must have seemed ideal for the purpose, they did not use it to determine the date of mid-season, employing it only for observation of the equinox, for which it possessed unique advantages that more than offset the difficulties. For the mid-season observations, they selected a more convenient location.

To these observers, any site with a reasonably good eastern horizon would have seemed acceptable. Counsel Rocks itself was not a suitable location, since at this site the sun, at the summer solstice, rises behind a peak on the northeastern horizon. The observations could have been made from a point a short distance to the south of Counsel Rocks, where the skyline is relatively uniform in altitude from the summer solstice to the equinox sunrise points. However, from the observers' point of view, they already had an even better location: Shelter Rock. After all, they were already making summer solstice sunrise observations there and it had the advantages of being easily accessible from Counsel Rocks, of having a reasonably good horizon from the equinox to the summer solstice sunrise points, and of having a shelter where the observer could wait for and observe the sunrise in comfort, sheltered from the cold persistent wind and (occasional) rain. It also had a well-defined summer solstice sunrise point—the skyline V discussed in the second section—and various small peaks, knobs and notches along the eastern horizon that could be used as reference markers for the positions of the equinoctial and mid-season sunrises, eliminating the need to lay out sight lines to the sunrise points.

At Shelter Rock, the observers would most likely have proceeded as follows:

(1) The location of the equinoctial sunrise point as seen from Shelter Rock would have been determined from observations of the equinox with the cairn gnomon on Barrier Hill. Averaged over time, these observations, if carried out only at the vernal equinox, would have given them the sunrise point when $\delta_{\odot} = -0^{\circ}\,06'$, as discussed in the fourth section. The geometry of the equinoctial sunrise at Shelter Rock is illustrated in Figure 60. This figure, traced from a photograph, shows the eastern skyline as viewed from the platform directly above the Shelter Rock overhang. The circles indicate the solar disk and the inclined lines show the path of the center of the disk on successive days, day zero indicating the path when $\delta_{\odot} = -0^{\circ}\,06'$ at sunrise. Dots indicate the position of the center of the disk when its upper limb first emerges above the skyline. The horizontal line is an arbitrary level line. The figure shows that one day before the vernal equinox the sun rises near the top of the equinox slope, and on the day after the equinox, at the northern base of that slope. The slope itself is rather featureless. The observer has

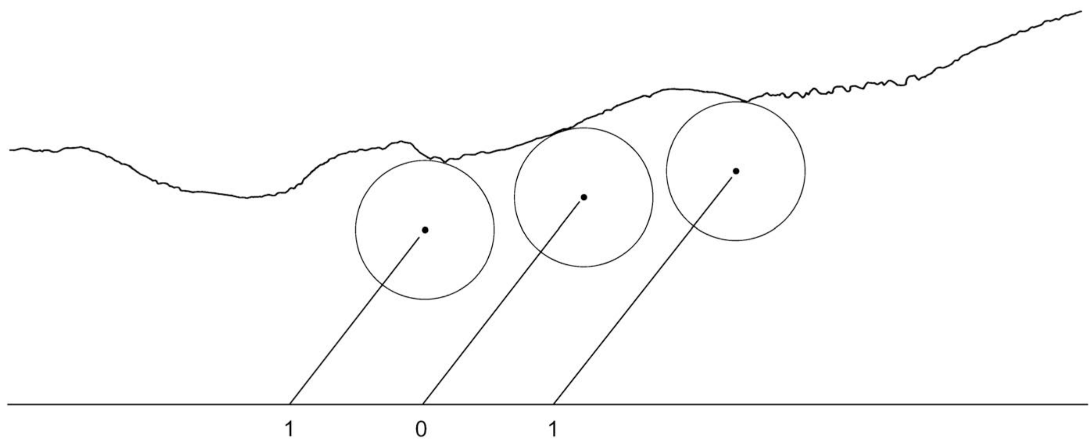

Figure 60. Geometry of the equinoctial sunrise as seen from Shelter Rock. Eastern skyline traced from a photograph. Horizontal line is an arbitrary level line. Circles indicate the solar disk, 32′ in diameter, and the inclined lines the path of the center of the disk on successive days, day zero indicating the path when $\delta_\odot = -0°\,06\overset{\prime}{.}2$ at sunrise. Dots indicate the center of the disk when its upper limb first appears above the skyline. Disk locations based on photographic observations of the sunrise point.

only one or two seconds to estimate the position of the sunrise point before all detail is lost in the increasing glare of the solar disk. Consequently, the best he would have been able to do would have been to estimate, roughly, the fractional position of the sunrise point along the slope. Since, as Figure 60 shows, the equinox sunrise position is near the midpoint of the slope, he would likely have adopted the midpoint of the slope as being the equinox sunrise position.

(2) The observer would have next determined the angle between the equinoctial and solsticial sunrise points. Since it was not possible at Shelter Rock to lay out lines of sight to the skyline points on the ground, the observers most probably made use of a "cross staff" to measure the equinox–solstice angle. This "cross staff" could have consisted of two pieces of wood fastened together to form a "T," and supported on tripods at its three extremities. The observer sighted from the base of the T, through a defining slot or aperture, to reference markers placed along the crossbar of the T so as to align with the required points on the skyline.

Quite good accuracy can be obtained even with a relatively small cross staff. As a test, a T having a length from the eye point to the crossbar of $L = 2.80$ m was constructed. To cover the angle between the equinox and solstice sunrise points, a crossbar length of about 1.19 m would have been required. On axis, an angle of $0°\,01\overset{\prime}{.}0$ corresponds to 0.81 mm, while at the ends of the bar, it equals 0.84 mm. Straight, slender cactus thorns could have been used as marking pins on the crossbar; at Shelter Rock, such thorns can have diameters of $\simeq 0.5$ mm. The tests showed that at $L = 2.80$ m, a 0.5 mm diameter thorn is nicely visible as a black line against an illuminated skyline. At the eye end of the T, an exit slit with a width of 0.5 mm still gives a well-illuminated and sharp image of the skyline. The foresight thorn can easily be kept centered in the exit slit to $\leqslant 0.1$ of the width of the slit during the observations, or $\leqslant 0.05$ mm. Thus the parallax error due to misplacement of the observer's eye is $\leqslant$ $00'.06$. Consequently, the error in the measured angle between the equinoctial and solsticial sunrise points would have been set by the accuracy with which the markers could be positioned on the crossbar.

If the mid-season observations were made no earlier than A.D. 1450, the solstice sunrise point would almost certainly have been considered to be the solstice V, even though Figure 5 shows that at that time the V had a larger azimuth than that of the center and upper limb of the solar disk at sunrise. As pointed out in the second section, the V narrows down to a notch only two arc minutes in width. Thus, the marker on the crossbar could have been aligned to it with an accuracy of $\simeq 0.5$ mm, or $\simeq 00'.6$ for $L = 2.80$ m. As discussed above, the equinoctial sunrise point was probably taken to be the midpoint of the equinox slope. The location of that midpoint might have been determined by first placing markers on the crossbar, aligned with the top and bottom ends of the slope. A short, straight stick was then prepared, and two markers placed on it having a separation, s_1, slightly less than $S/2$, where S was the separation of the two slope markers on the crossbar. This distance was then marked on the crossbar, measuring inward from the two slope markers toward their midpoint. The separation of the stick markers was then changed to $s_2 = s_1 + \Delta s_1/2$, where $\Delta\, s_1$ was the distance between the two "s_1" markers on the crossbar. The new distance, s_2, was then measured inward from the two slope markers on the crossbar, and the positions of the "s_1" markers on the crossbar readjusted to the new distance, s_2. This procedure was then repeated until, after n repetitions, $s_n = S/2$. This procedure would probably have yielded the midpoint of the slope with a formal linear accuracy of ± 0.5 mm, although the actual error might have been larger since the positions of the ends of the equinox slope are not sharply defined.

(3) Once the solsticial and equinoctial sunrise points had been po-

sitioned on the crossbar, the direction of the mid-season sunrise point was found by locating the midpoint of the distance between them. This would probably have been done using the procedure outlined in (2) above, and would have located that midpoint on the crossbar with an uncertainty of $\simeq 0.5$ mm. Thus, depending on the linear dimensions of the "cross staff" used, and assuming that the direction to the mid-season sunrise point lay along the axis of the T, the error in that direction could have been as small as one or two minutes of arc.

The angle between the solstice notch and the midpoint of the equinox slope at Shelter Rock was measured using a surveyor's transit. In these measures, the midpoint of the equinox slope was assumed to be half way between the top of the slope and the bottom of the last dip in the skyline at the north end of the slope, just before the skyline rises up to the small knob located just to the left of center in Figure 60. The original observers, however, might have considered the north end of the slope to be the bottom of the slightly deeper skyline dip situated $03\overset{\prime}{.}2$ south of the one just described. If so, they would have located the slope midpoint $\Delta\ A = +01\overset{\prime}{.}6$ south of the position adopted here. Furthermore, as the figure shows, the peak at the south end of the slope is rather flat, so that the azimuth of the upper end of the slope is uncertain by some three or four minutes of arc. Thus, while the errors of the transit settings were about one minute of arc, the uncertainty in the azimuth of the midpoint of the slope may he somewhat larger.

The transit observations show that the bisection point of the equinox–solstice sunrise angle lies along the southern slope of a tent-shaped peak on the eastern skyline. This peak is shown in Figure 61, which reproduces a tracing of the skyline from a photograph, once again taken, like that in Figure 60, from the platform above the Shelter Rock overhang. The bisection point is indicated in the figure by the northernmost of the three tick marks appearing just above the skyline on the south side of the peak. As the figure shows, this point occurs very close to the center of that portion of the southern slope which lies above the vertical cliff. The midpoint of this upper slope is shown by the middle tick mark. The southernmost tick mark indicates the sunrise point when $\delta_\odot = +\epsilon/2$ ($\delta_\odot = +11^\circ\,43\overset{\prime}{.}2$) at sunrise, as derived from a photograph of the sunrise on August 22, 2004. Note that since the position of the mid-season sunrise point is based on a single sunrise observation, errors of several minutes of arc in the azimuth of this point could be present due to the effect of anomalous refraction.

The geometry of the mid-season sunrise is shown in Figure 61. In the figure, the circles indicate the diameter of the solar disk ($32'$) and its position at the moment of sunrise. The centers of the disks are indicated by dots, while the diurnal paths of the centers are shown by the inclined lines; the horizontal line is an arbitrary level line. The middle circle, with the diurnal path labeled zero, shows the location of the solar disk when the sun rises at the midpoint of the

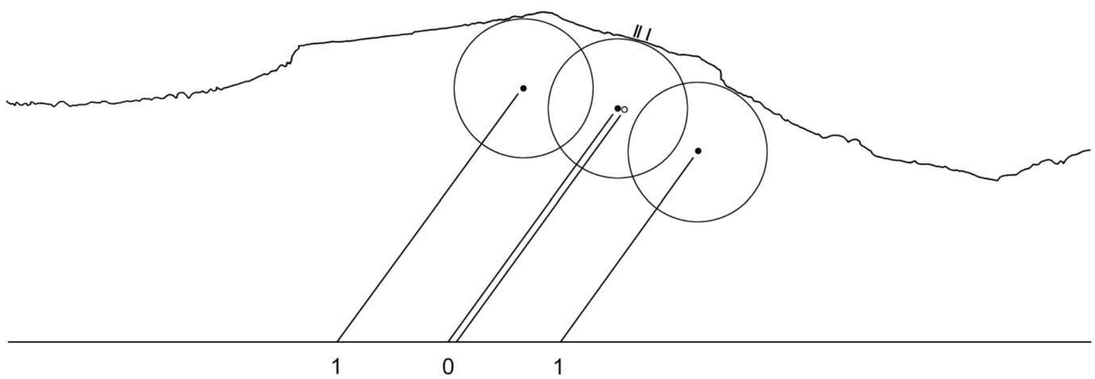

Figure 61. Geometry of the mid-season sunrise as seen from Shelter Rock. The figure shows the skyline traced from a photograph. The horizontal line is an arbitrary level line. The three tick marks above the skyline show (from north to south): 1) The bisection point of the solstice–equinox sunrise-point angle as measured with a surveyor's transit. 2) The midpoint of the upper slope of the peak. 3) The sunrise point when $\delta_\odot = +\,\epsilon/2$ at sunrise. Circles indicate the solar disk and its position at the moment of sunrise. Centers of the disks are shown by dots, and the diurnal paths of the centers by the inclined lines. The middle circle shows the location of the solar disk when the sun rises at the midpoint of the upper slope. The other circles show the position of the sun one day before and after the mid-slope sunrise. The small circle indicates the center of the solar disk when $\delta_\odot = +\,\epsilon/2$ at sunrise.

upper slope. The other two circles, with paths labeled one, indicate the positions of the sun one day before and one day after the mid-slope sunrise. The small circle indicates the center of the solar disk when $\delta_\odot = +\epsilon/2$ at sunrise, and shows that when the sun rises at the midpoint of the upper slope, $\delta_\odot = +11^\circ\,45'$, or + $\epsilon/2 + 2'$. As Figure 61 shows, the bisection point lies only $\Delta\,A = -01\overset{\prime}{.}1$ or + $00\overset{\prime}{.}5$ from the midpoint of the upper slope, depending on which point is chosen as the north end of the equinox slope, although the original observers might have found a somewhat larger difference, depending on where they located the south end of the slope. Still, it is evident that however they defined that slope, bisecting the angle between the midpoint of the equinox slope and the solstice V would have brought them to a point close to the middle of the upper slope on the south side of the mid-season peak. Consequently, they would almost certainly have simply adopted the midpoint of the upper slope as marking the true position of the mid-season sunrise, just as they had done previously for the position of the equinox sunrise.

When the sun rises at the midpoint of the upper slope, then at midday when the sun's ray passes through the petroglyph circle, the daily motion will (at present) have moved the sun to $\delta_\odot = +11^\circ\,50'$ in April when it is moving northward, and to $\delta_\odot = +11^\circ\,39'$ in August when it is moving southward. However, if observations in April and August are combined, then at midday the average position of the ray will correspond to $\delta_\odot = +11^\circ\,45'$ or + $\epsilon/2 + 2'$. As noted above, the sun's ray now bisects the circle when $\delta_\odot = +11^\circ\,41'$ or + $\epsilon/2$ $-02'$ $\pm 2'$. The agreement between the center of the circle and the averaged center of the ray is thus extremely good, the difference between them corresponding to $\Delta\ \delta_\odot = 0^\circ\,04'$, or only 1.7 mm on the rock surface.

Figure 61 shows that, owing to the particular geometry of the mid-season sunrise, the sun will rise along the upper slope of the mid-season peak only when $+\ 12^\circ\,02' \geqslant \delta_\odot \geqslant +11^\circ\,34'$ at sunrise. In most years the sun will rise along the upper slope of the mid-season peak on only one day. That day would then have been considered to be mid-season day, and the path of the center of the sun's ray at midday marked in the Rock 4 cavity. However, occasionally the sun will rise along the slope on two successive days. In this case, the day when the sun rose closest to the midpoint of the slope would have been chosen; if the sun rose at essentially equal distances north and south of the midpoint on two successive days, the observations would probably have been omitted. Eventually, the paths marked in Rock 4 would have been averaged to give the final position of the center of the petroglyph.

As a test of this procedure, solar declinations at sunrise in April and August for the years 1996–2003 were calculated from the *Astronomical Almanac*. Only sunrise points lying $\leqslant 1/3$ of the distance from the midpoint to the ends of the upper slope were included. The corresponding solar declinations at midday were then calculated and these values averaged, giving $\delta_\odot = +11^\circ\,44\overset{\prime}{.}4$, which differs from $+\ \epsilon/2$ by $\Delta\ \delta_\odot = +0^\circ\,01\overset{\prime}{.}2$.

The close agreement between the center of the petroglyph circle and the center of the sun's ray when $\delta_\odot = +\epsilon/2$ at sunrise would appear to confirm that the petroglyph was indeed located using the procedures outlined above. It also strongly suggests that observations of the mid-season day sunrises in both April and August were used in that process. Use of both April and August observations is what we would expect: since there were only two days in the year on which these observations could be made, the observers would naturally have made use of both opportunities. It would have been possible for them to do this since water is still available at the site in August, whereas it is no longer present by the time of the autumnal equinox in September, as discussed in the previous section.

As discussed earlier, at a site where the altitudes of the summer solstice, mid-season and equinox sunrise points are all $h = 0^\circ\,00'$, the mid-season sunrise azimuth does not lie precisely half way between those of the solstice and equinox sunrises. At Shelter Rock, if $h = 0^\circ\,00'$, the azimuth of the mid-season sunrise point will differ from that of the bisector of the solstice–equinox sunrise angle by about 12 minutes of arc. For the mid-season sunrise to occur exactly half way between the equinox and solstice sunrise points, calculations show that values of the skyline h must be chosen such that h increases slightly from the equinox to the solstice. This is the case at Shelter Rock, where observations with the surveyor's transit give horizon altitudes of $h \simeq +0^\circ\,14'$, at the equinox, $h \simeq +1^\circ\,00'$ at mid-season, and $h = +1^\circ\,56'$ at the summer solstice sunrise points, and it is for this reason that the sunrise-point bisection method gives the correct result at that site.

The observers clearly used great ingenuity and care in determining the date of mid-season and in the placement of the petroglyph circle. However, the almost perfect alignment of the circle with the sun's ray when $\delta_{\odot} = +{}^{\epsilon}\!/_{2}$ was entirely accidental, and resulted simply from their choice of Shelter Rock as a convenient and comfortable location from which to make their observations of the sunrise angles.

6

Summer Solstice at Counsel Rocks

As discussed in the preceding section, Rafter's Rock 4 at Counsel Rocks (Rafter 1985) contains a cavity into which a ray of sunlight penetrates near midday. On mid-season day, this ray has the form of a narrow finger of light which bisects the mid-season petroglyph circle. At the summer solstice, the ray appears as a broad band of light extending approximately east to west, as shown in Figure 62. This band is slightly wedge shaped, with a notch in its eastern end. At a distance of about 5 cm from the bottom of the notch, the north–south width of the band is about 12 cm.

As this band of light traverses the floor of the cavity, it illuminates a barely visible feature on the rock surface. This feature has the appearance of the remains of a pecked ring having an outside diameter of 6 cm and an inside diameter of 4 cm. The ring can be traced as a shallow groove in the surface of the rock. The groove and the interior of the ring appear very slightly less patinated than the surrounding rock surface. Whether this feature is natural or man made is uncertain. If it *is* a petroglyph, then its degree of patination and the eroded state of its surface would indicate that it is very old. Significant deterioration of that surface with time would be expected since the location of the ring, on the floor of the cavity, is fully exposed to the effects of the weather.

As indicated, the overall outline of the band of light is slightly wedge shaped. It is also somewhat irregular. However, for the first 7 cm at its eastern end, behind the notch, the sides are reasonably straight. If the band were to be used to indicate the declination of the sun, this would be the logical portion to use. Reliable measures could be made for a period of about seven minutes after a particular reference point on the rock surface first became illuminated. Considering this portion of the band, Figure 62 shows that at the solstice, the center line of the band lies just slightly north of the center of the circular feature. Measurements of this displacement on the rock surface, d, were made on two photographs. The first was taken when the east end of the band was just at

Figure 62. Possible ancient petroglyph on floor of Rock 4 cavity at Counsel Rocks, illuminated by band of sunlight at the summer solstice. North at the top, east to the right. See text. Outer diameter of the petroglyph circle = 6 cm.

the eastern edge of the ring, and the second two minutes later. These measures give an average displacement of $\overline{d} = 1.22 \pm 0.03$ cm. The distance of the feature from the entrance aperture is 243.5 cm. Thus the observed displacement, $\overline{d}$, corresponds to a change in the solar declination of $\Delta\ \delta_\odot = -0^\circ\, 17\overset{\prime}{.}2 \pm 00\overset{\prime}{.}4$ (or slightly less, if the rock surface is not exactly perpendicular to the direction to the entrance aperture). Thus at the time, T, when the band was centered on the circular feature, $\epsilon_T = +23^\circ\, 43\overset{\prime}{.}5$, and from Appendix 2, $T = 250 \pm 50$ B.C.

Experiments with full-scale layout drawings of the petroglyph circle and the band of sunlight indicate that de-centering of the circle within the sunlit band first becomes detectable with a displacement between the centers of the circle and the band path of about 1.8 mm. This distance corresponds to $\Delta\ \delta_\odot = -0^\circ\, 02\overset{\prime}{.}8$. Thus, when $\epsilon \geqslant \delta_\odot > (+\epsilon - 0^\circ\, 02\overset{\prime}{.}8)$, the diurnal path of the band across the circle appeared to remain unchanged. Since $\delta_\odot > (+\epsilon - 0^\circ\, 02\overset{\prime}{.}8)$ for about $3\overset{\mathrm{d}}{.}6$ before and after the solstice, the path of the band appeared to remain the same for a total of about seven days. Consequently, using the petroglyph, the date of the solstice could probably not have been determined with an error less than several days. It is likely, therefore, that the actual date of the solstice was determined from sunrise observations before and after the solstice, as described in the second section, and that the feature in Rock 4 was used mainly for ceremonial purposes.

If sunrise observations were used, then the solstice notch at Shelter Rock might well have been utilized to determine the date of the solstice. Table 1 shows that in 250 B.C. the sun rose in or north of the notch for $N = 20\overset{\mathrm{d}}{.}5$. Thus the sun began to rise in the notch about nine days before the day of the solstice, and this event would have provided a very accurate and timely indication of the solstice date. And, as we have seen in the second section, certain ceiling pictographs in the Shelter Rock overhang do in fact suggest that summer solstice sunrise observations were being made there at about this time. The solstice sunrise itself, occurring some eight minutes of arc—or one quarter of the diameter of the solar disk—north of the notch, would not have been particularly impressive, and a petroglyph in Rock 4 might have appeared more interesting for ceremonial purposes.

It is noteworthy that there is no *latter-day* solstice marker in the Rock 4 cavity dating from the later period when the mid-season petroglyph was inscribed. By that time, the sun no longer rose to the north of the notch at Shelter Rock, but rose in the notch itself, thus providing, as we have seen, a much more spectacular solstice event than that produced by the band of sunlight in Rock 4.

7

Discussion and Conclusions

The present studies confirm Rafter's (1985, 1987, 1991) conclusion that calendrical observations of the sun were carried out at Counsel Rocks and Shelter Rock, and indicate that they were conducted atop Barrier Hill as well. They further indicate that these observations were quite sophisticated in their concept and were made with a high degree of precision.

The Barrier Hill gnomon is particularly noteworthy. Its unique design demonstrates an understanding of the properties of gnomons on a par with—and indeed, probably more advanced than—that of the ancient Babylonian, Egyptian, or classical Greek astronomers; so far as I am aware, there is no record of these astronomers constructing a south-pointing gnomon for the specific purpose of determining the date of the equinox, as was done at Barrier Hill. The basic idea of this type of gnomon may have originated through an observant toolmaker or hunter being struck by the conical shadows cast, in sunlight, by projectile points (or perhaps the flakes of chalcedony from which they were being made) when turned southwards. He might then have been led to experiment with small pieces of wood or stone of various shapes. These experiments would have soon revealed the properties of such a pointer.[11] The Barrier Hill gnomon would have then been constructed and, once in place, modified in shape to produce the optimum shadow cone. That is, a cone symmetric in form and with its axis in the direction of its diurnal motion near the date of the equinox, thereby maximizing the accuracy of measurement of the curvature of the shadow path.

The use of the sun's position when $\delta_\odot = +\epsilon/2$ as a mid-season marker likewise shows a considerable degree of sophistication when one considers that the prehistoric and medieval peoples of the British Isles were content to define such dates by merely dividing in half the number of days between the equinoxes and solstices. Using the midpoint solar declination, found by dividing in half the angle between the equinox and summer solstice sunrise points, is a much more elegant concept. As we have seen, the fact that the mid-season petroglyph is bisected by the sun's ray precisely when $\delta_\odot = +\epsilon/2$ is the chance result of the observers' choice of Shelter Rock as the place from which to make their sunrise observations. However, the fact that doing so resulted in that precise alignment shows the observers' skill and dedication to achieving the highest possible accuracy in their measurements. It also suggests that the use of $\delta_\odot = +\epsilon/2$ to define mid-season day began only within about the last 500 years.

The observers' ingenuity and flair for precision is shown not only by their conception, design and shaping of the Barrier Hill equinox gnomon and the care that they took in positioning the mid-season petroglyph, but also by:

(1) Their use of horizon or skyline Vs to provide accurate dates of the solstices.
(2) Their recording of the sunrise/sunset day counts from the rising or setting of the sun in the Vs to the solstices, and their discovery of, and correction for, the changes in these day counts with time.
(3) The care with which the sun symbols, the mid-season petroglyph, and the petroglyph on the southeast face of Rock 3 were constructed, shaping them so that they appeared perfectly circular as viewed by their painter or engraver.

In addition to understanding the use of observations of the sun to determine accurately the dates of the solstices, equinoxes and mid-season, it appears that some of the inhabitants of the region may also have been aware of the phenomenon of magnetism. Studies by the writer (Walker 2007) suggest that observers at the nearby site CA–SBR–528 used a lodestone to detect and mark lines of anomalous magnetization across the surface of a rock which had been struck by lightning. The date of these magnetic observations is unknown. However, the fact that the petroglyphs marking the magnetic anomalies show little patination indicates that they are not extremely old.

The sunrise observations at Shelter Rock and the mid-season and sunset observations at Counsel Rocks all appear to have been carried out during one or both of two distinct time periods, which were separated by an interval of many centuries. This is shown not only by the interpretations of the pictographs and petroglyphs discussed above, but also by the degree of patination of all of the petroglyphs at Counsel Rocks and the surrounding region. Instead of exhibiting a continuous range in their degree of patination, these petroglyphs form two distinct groups. One group is heavily patinated and clearly very old. The other exhibits only slight patination, and is obviously much younger. This division is illustrated in Figure 19, which shows the north wall of the main cavity in Rock 3. Here, the horizontal line at the right-hand end of the cavity wall is relatively unpatinated, while other petroglyphs further to the left in the Figure have a patination nearly the same as the surrounding rock surface. At Counsel Rocks, in addition to the feature just described, the petroglyph on the outside of Rock 3 and the mid-season and other petroglyphs in the Rock 4 cavity belong to the second, lightly patinated, group, as do the lightning-related petroglyphs near CA–SBR–528. Thus, all of these petroglyphs would appear to be no more than some hundreds of years old.

Another example of this differential patination is found on the rock near CA–SBR–528, discussed above. In addition to the relatively unpatinated lightning-related petroglyphs, this rock also has an extremely old, heavily patinated petroglyph, as described by Walker (2007). That symbol consists of three concentric circles with a vertical line descending from the innermost circle to well beyond the outer one. Applying Martineau's (1973:100–101) precepts and translations, a series of concentric circles means "many holding (staying) in one place," and a radial line descending from the innermost circle of such a symbol indicates that "all of what were holding in one place are gone;" if not all were gone, the line would descend from an intermediate circle. Since there are only three concentric circles, the meaning of the petroglyph may be that the number that were holding was not large. The patination of this symbol is so extreme that it can now only be detected under the most favorable lighting conditions, *i.e.*, when illuminated by sunlight striking the rock face nearly perpendicularly, which occurs only just before sunset near the date of the winter solstice. This petroglyph thus belongs to the first, heavily patinated group, and is clearly many centuries older than the lightning-related petroglyphs. It may, therefore, memorialize the end of the first (or earlier) period of occupation of the region, stating very starkly that those (people) who were staying (living) here—not a large number—are all gone. There is no indication of why they are all gone or where they have gone to. However, the length of the gone line, extending far beyond the outer circle, may indicate that they have gone far away. The reasons for the abandonment of the Shelter Rock and Counsel Rocks sites at the ends of both the earlier and later periods of activity remain uncertain. One possibility is that the earlier observers were forced to leave as a consequence of the eruption of Krakatoa (or a nearby precursor volcano) in A.D. 535, which produced world-wide climatic and social upheavals (Keys 2000). If not forced out by the immediate effects of the eruption, the observers may have been driven away at a somewhat later date by the generally below-average precipitation which the region experienced from A.D. 535 until about A.D. 1400, with particularly severe droughts near A.D. 924 and 1299 (Stine 1994). Beginning in A.D. 1400, precipitation tended to be, on average, above normal until the onset of the sixteenth century multi-decadal drought, which lasted from about A.D. 1565–1598 (Woodhouse and Overpeck 1998). Thus, observers may have returned about A.D. 1400 when water once more became available at or near the sites, and remained until once more driven forth by drought in the late sixteenth century. Alternatively, the final cessation of observations at the two sites might have resulted from the incursion of the Spanish into the region, resulting in the end of the old traditions of observing the sun.

Whatever the precise details, the picture that emerges from these studies is that of a region in which a series of skilled, highly intelligent and inventive observers were active during at least two distinct periods of time, the first seemingly occurring sometime between around 500 B.C. and A.D. 400–800, and the second from about A.D. 1450 to A.D. 1610–1750. It was a very special region, most probably of high ceremonial significance. It contained natural wonders such as the summer solstice sunrise phenomena at Shelter Rock and the winter solstice events at Counsel Rocks, as well as a magic rock which could attract a lodestone. In addition, it had an instrument for the precise determination of the dates of the equinoxes, and a very accurate marker for mid-season day.

The region may have been occupied only seasonally, owing to a lack of water in the late summer and fall, although it is of course possible that the springs that now provide water in the winter, spring and early summer once flowed all year. In any case, the presence, at Counsel Rocks, of both slightly and heavily patinated petroglyphs, extensive midden deposits, in at least one area reaching to a depth of 1.2 m below the surface (Desautels and McCurdy 1969:67–68, 128–129, as cited in Trupe et al. 1988), and rock surfaces and petroglyphs polished by centuries of human contact indicate that *this* site, at least, was used extensively, and over long periods of time.

Who these observers were is not clear. The last people to occupy the region were the Chemehuevis (Kroeber 1925:593–595, Laird 1976:7). Originally, the Chemehuevis lived an entirely nomadic life, hunting and gathering throughout the Mojave Desert (Kroeber 1925:593–595, Laird 1976:4, 5, 7). Later, after A.D. 1776 (Kroeber 1925:593–595), they farmed the bottom lands of the Colorado River valley for part of the year, living in settlements along the river from about May–October, and then resuming their nomadic hunting and gathering life from November–April (Laird 1976:23). From the map published by Laird (1976:inside rear cover), it appears that Counsel Rocks is situated along one of the Chemehuevi trails from the Colorado River northwestwards across the eastern Mojave Desert. This conclusion would appear to be reinforced by two "bighorn sheep" petroglyphs located on the western face of Rafter's (1985) Rock 1. Photographs of these symbols are reproduced in Figure 63. One of these petroglyphs, shown on the left in Figure 63, is located at the northern end of the rock and faces north. The other, shown on the right of the figure, is situated more towards the southern end and faces south. Martineau (1973:11) holds that this type of petroglyph is not simply a representation of a bighorn sheep but is, rather, a symbol in the Indian pictographic language, in which a quadruped form is a means of indicating action or direction. In the present examples, the sheep's "horns" are actually two parallel arcs. Martineau (1973:48–50) states that a doubled arc has the meaning of nothing there (in the sense of no hindrance), and thus good. Attached to the head of the quadruped, they indicate no hindrance to movement or journey in the indicated direction. Consequently, these two bighorn sheep petroglyphs may well be trail markers, indicating the directions of the trail as it leaves Counsel Rocks, and stating that it is a good trail (Martineau 1973:48–50) in both directions. These petroglyphs are only very slightly patinated, being just detectably darker than a freshly pecked line in a sample of the same material as Rock 1, but less patinated than the adjacent light-colored areas of the Rock 1

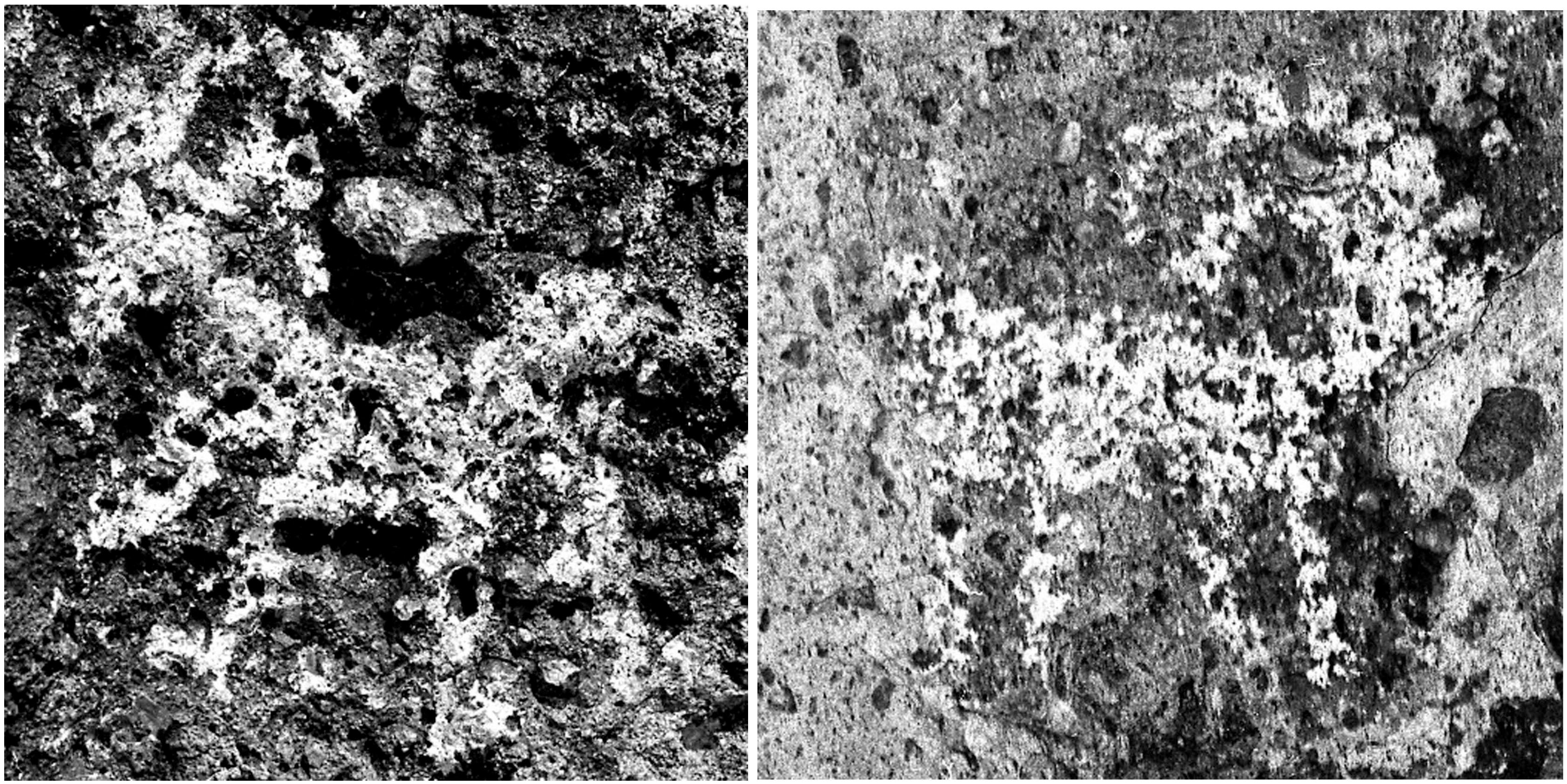

Figure 63. Bighorn sheep petroglyphs on Rock 1 at Counsel Rocks. Left: Northern, north-facing sheep. View width is 14.0 cm. Right: Southern, south-facing sheep. View width is 21.3 cm. See text.

surface, as can be seen in Figure 63. Thus, while they were not created recently, they are also not extremely old, and are clearly very much younger than other, more heavily patinated petroglyphs on the same rock face. Moreover, it is likely that they were placed there at a time when Counsel Rocks was no longer frequently inhabited, as was apparently the case during at least the latter part of the Chemehuevi period. If people had been living at Counsel Rocks, they would have been able to provide the traveler with any necessary information regarding the trail, rendering trail markers unnecessary.

One further possible connection of the Chemehuevis to Counsel Rocks is provided by the (more or less unpatinated) petroglyphs within the cavities in Rafter's Rocks 3 and 4. As pointed out by Rafter (1985), these petroglyphs appear to depict the Chemehuevi myth of *The Lone Woman of the Cave* or, as Laird (1976:161–162) titles it, *The Twin Sons of the Sun* or *The Sun's Dead Sons* (Laird 1984:204–207). The Chemehuevi myth concerns the sun as a god who could assume human, or partly human, form. In the petroglyph panel within the Rock 4 cavity, the sun is, according to Rafter (1985), represented by a wagon wheel symbol, consisting of two concentric circles, one large and one small, with seven radial spokes connecting them. This symbol may thus refer to the sun as a god or spirit, consistent with the myth, as distinct from the actual astronomical sun, typically represented (as at Shelter Rock) by a circle or disk with external rays. This interpretation of that symbol is reinforced by a petroglyph in Renegade Canyon, shown in the photograph reproduced in Figure 64. That petroglyph depicts an anthropomorphic figure whose head is the same wagon wheel symbol seen in Rock 4, and who is depicted holding a conventional sun symbol (disk with rays) with the right hand, thus controlling the (actual) sun.

According to Laird (1984:352–353), the Chemehuevis had words for the solstices, equinoxes and mid-seasons. However, the dates of these events were determined from the helical risings of certain stars (Laird 1976:93–95). Determining these dates in that way is consistent with the Chemehuevis's known nomadic life style, which would have prevented them from using horizon markers and sunrise (or sunset) observations for this purpose. Yet it is clear from the present study that, particularly during the second period from A.D. 1450–1750, observers had to have been in residence at Counsel Rocks from at least about the middle of December to the middle of August for a good many consecutive years. Moreover, these observers not only had a good understanding of the concepts and associated phenomena of the solstice, equinox and mid-season, but were dedicated to the precise timing of these events through observations of the sun.

It appears unlikely, therefore, that these second-period observers were Chemehuevis living the nomadic life style described by Kroeber and Laird. They may have been members of a different group that lived in the region during that time. Or, if they were Chemehuevis, then at one time, perhaps before their move to the Colorado River (which, interestingly, occurred not long after the time that the solstice observations at Shelter Rock and Counsel Rocks appear to have ceased),

Figure 64. Petroglyph in Renegade Canyon. Anthrophomorphic figure holding sun symbol with right hand. See text.

the Chemehuevis, or at least some subset of them, had a different life style, and a much more sophisticated level of astronomical and calendrical knowledge, than that reported by Kroeber and Laird.

Appendix 1

Shelter Rock Pictographs in Color

As discussed on page 3, the black and white illustrations of the pictographs in the Shelter Rock overhang reproduced in this volume were prepared using 35 mm color slides digitally scanned and manipulated to produce enhanced- or false-color versions that were then used as a guide to slightly suppress the natural coloration and markings on the rock surface. These computer-generated versions were then converted to grayscale to produce the black and white figures in the text. These procedures were carried out some years ago by the (now discontinued) Photographic Services of the University of California at Santa Cruz. Copies of several of the enhanced and/or false-color images used in this process are reproduced in the following color plates. These illustrations are identified by the numbers of the corresponding final modified black and white versions in the text.

PLATE I—Figure 4

Image should be viewed by turning page 90° clockwise

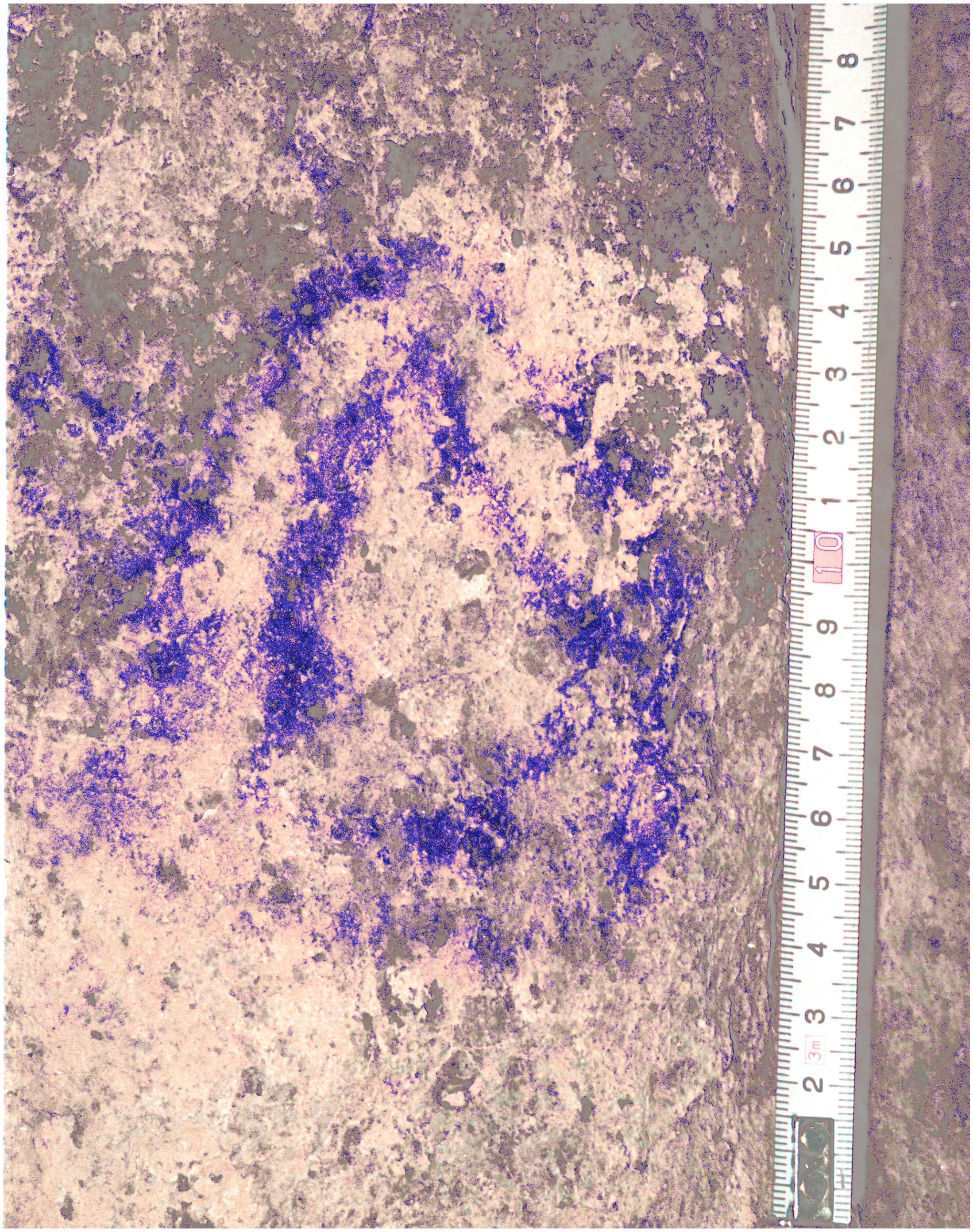

PLATE II—Figure 6, Version 1

Image should be viewed by turning page 90° clockwise

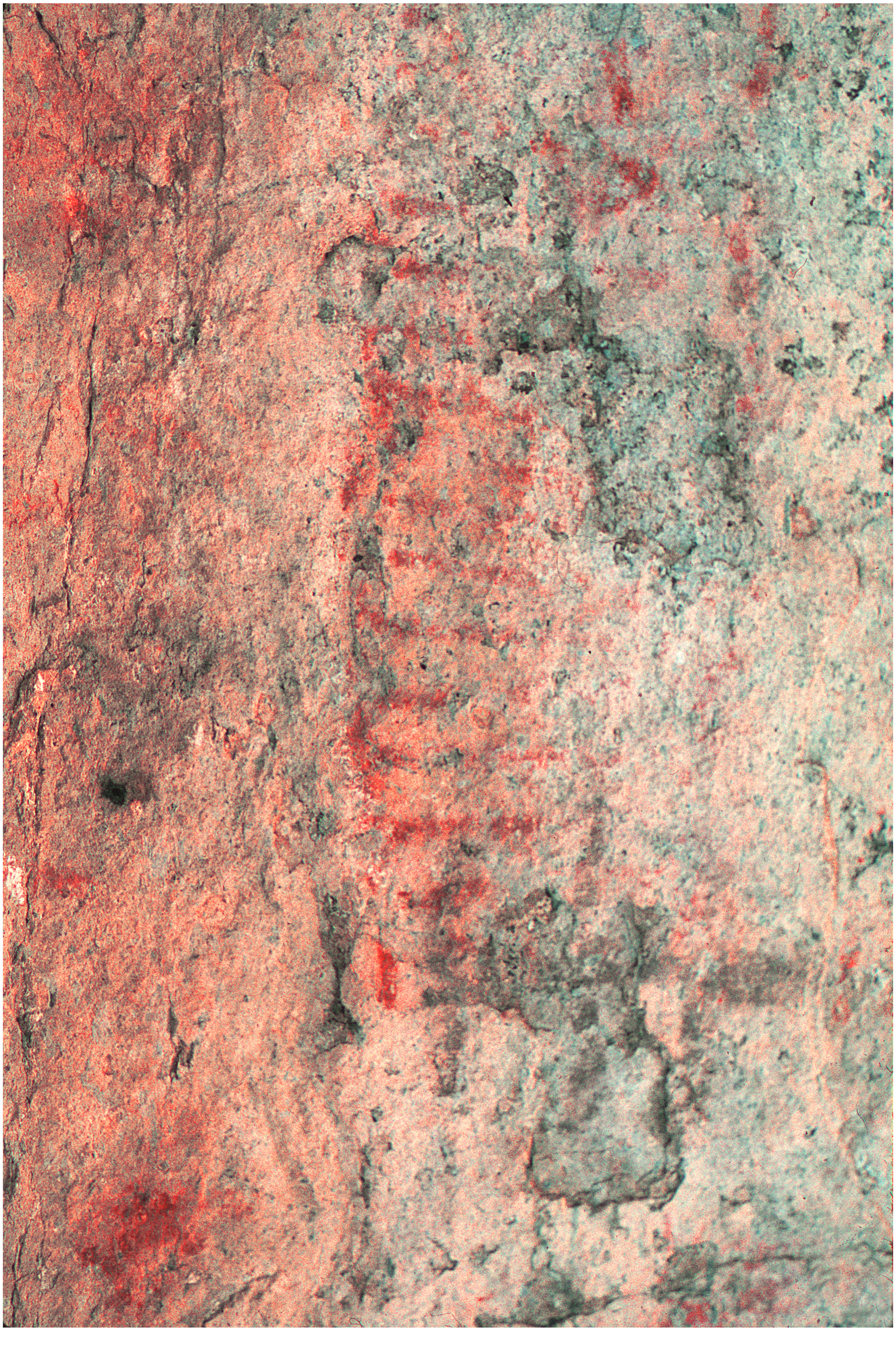

PLATE III—Figure 6, Version 2

Image should be viewed by turning page 90° clockwise

PLATE IV—Figure 10

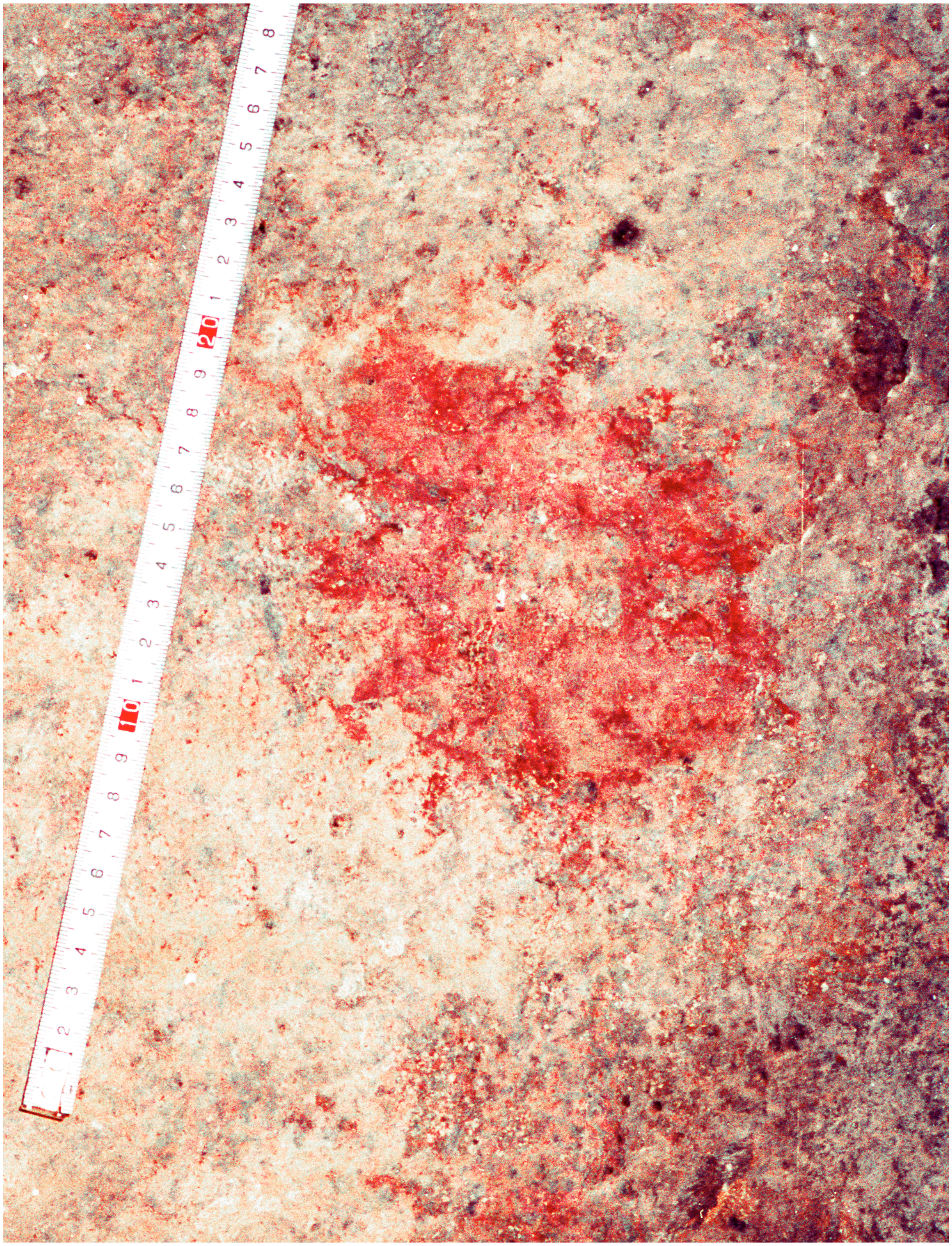

PLATE V—Figure 12

Image should be viewed by turning page 90° clockwise

PLATE VI—Figure 13

Image should be viewed by turning page 90° clockwise

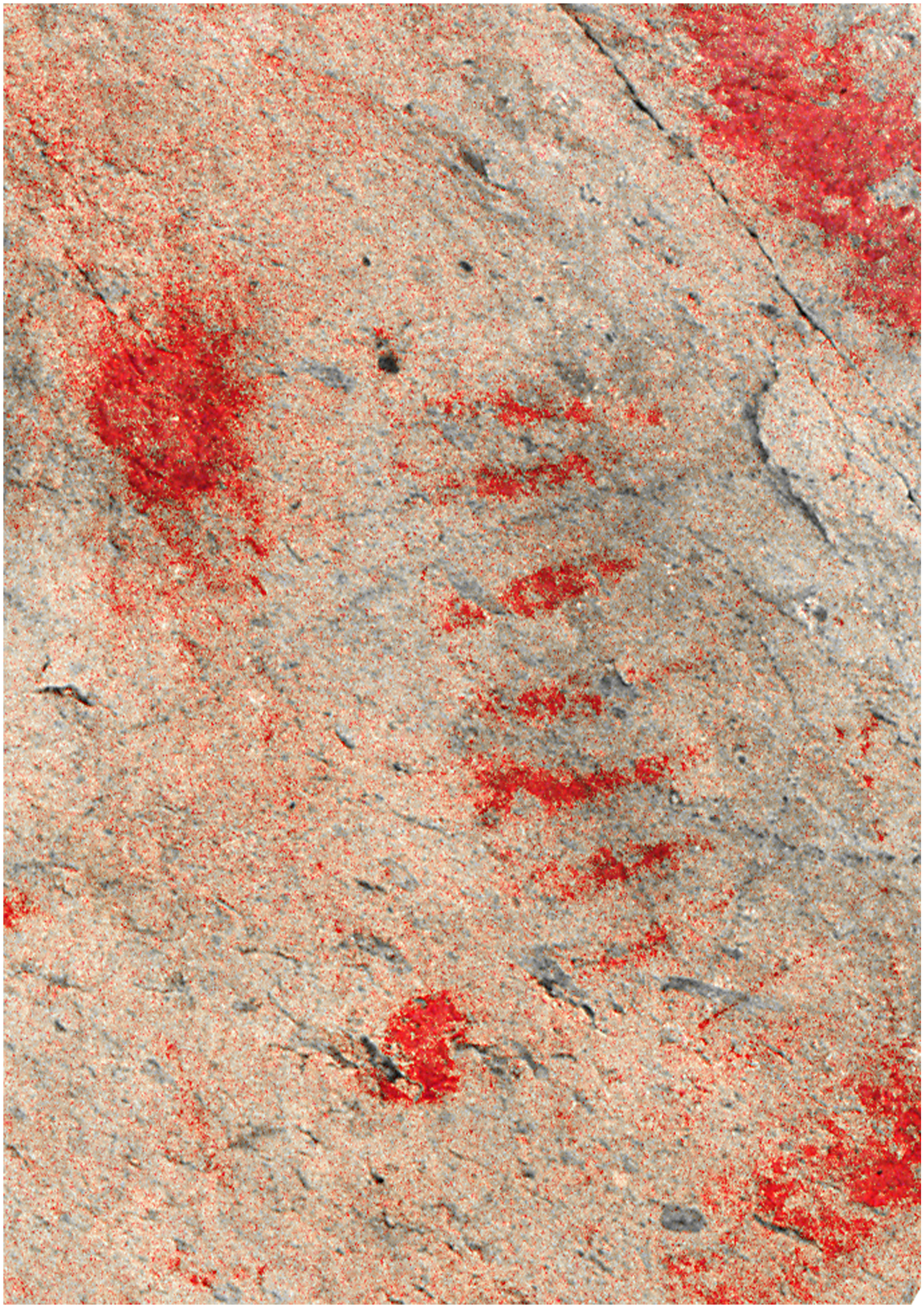

PLATE VII—Figure 15

PLATE VIII—Figure 16

Image should be viewed by turning page 90° clockwise

Appendix 2

Time Variation of the Obliquity of the Ecliptic and the Lengths of the Seasons

The obliquity of the ecliptic and the lengths of the seasons (the numbers of days between the solstices and equinoxes) both vary with time, owing to the perturbing effects of the moon and planets on the motion of the earth. In some instances, it may be possible to use these changes to date ancient astronomical observing sites. This technique has been used extensively in dating Stone Age astronomical sites in Europe. It is useful, therefore, to have available accurate tabulations of the obliquity and season lengths as functions of time, extending far enough into the past to encompass the earliest astronomically related sites.

Such a listing was very kindly prepared by the late Prof. Gibson Reaves of the Astronomy Department, University of Southern California, and is given in Table A–1. This table gives the values of the obliquity in degrees and the season lengths in days at 1,000 year intervals from 10,000 B.C. to A.D. 5000. The table was prepared from formulae and data published by Laskar et al. (1993). Laskar et al.'s solution is based on the numerical integration of an extended averaged system which represents the mean evolution of the orbits of the planets. Essentially, what is done is to start with the known positions of the earth, moon and planets at a particular time and calculate the combined attractive forces of these bodies on each other at that moment. All bodies are then allowed to move for a short time or distance along their orbits under the effects of these forces. Then, the gravitational forces are recalculated for these new positions and the bodies allowed to move another increment along their orbits under the effects of the revised forces. With modern computing capabilities, the step size can be made quite small so that high accuracy can be maintained over a time interval of some millions of years.

In Table A–1, the values of the obliquity were taken by Reaves directly from the values calculated by Laskar et al. (1993).[12] The season lengths were calculated by

Table A-1. Time Variation of Obliquity and Season Length

Epoch[a] Year	Obliquity Degrees	Lengths of the Seasons Number of Days Spring	Summer	Autumn	Winter
−10,000	24.159	88.8	89.3	93.9	93.3
9,000	24.206	89.4	88.7	93.2	93.9
8,000	24.230	90.2	88.3	92.4	94.4
7,000	24.231	91.1	88.2	91.5	94.5
6,000	24.209	92.0	88.3	90.6	94.4
5,000	24.166	92.8	88.6	89.8	94.0
4,000	24.102	93.5	89.2	89.1	93.4
3,000	24.021	94.0	89.9	88.6	92.7
2,000	23.924	94.3	90.8	88.4	91.8
− 1,000	23.814	94.3	91.6	88.4	90.9
+ 01	23.695	94.0	92.5	88.7	90.1
1000	23.569	93.4	93.1	89.2	89.5
2000	23.439	92.8	93.7	89.8	89.0
3000	23.310	92.0	93.9	90.6	88.7
4000	23.184	91.2	93.9	91.4	88.7
+ 5000	23.064	90.4	93.7	92.2	89.0

[a] B.C. epochs negative; A.D. epochs positive.

Reaves. First, the longitude of perigee referred to the mean equinox of date and the eccentricity (e) of the earth's orbit were taken from data files CLIVARON and CLIVAROP by Laskar et al. (1993). From these, the true anomaly (υ) was found for the solar angular distances from the vernal equinox of 0°, 90°, 180° and 270°. Next, the eccentric anomaly (E) was calculated as a function of υ and e, after which the mean anomaly (M) was found from Kepler's equation ($M = E - e \sin E$) and converted to days by taking the length of the year to be 365.25 days. The differences then yielded the lengths of the seasons. In Table A–1, the numbers have been rounded off to the nearest $0^\circ\!.001$ and $0^{\rm d}\!.1$, and thus have errors of $\leqslant \pm 0^\circ\!.0005$ and $\leqslant \pm 0^{\rm d}\!.05$. Linear interpolation in this table introduces an error of $<0^\circ\!.01$ in the obliquity and $<0^{\rm d}\!.1$ in the season length for all epochs.

Notes

[1] The visibility of these pictographs has diminished noticeably since the 1980s, possibly as a result of the increasing atmospheric pollution.

[2] Further confirmation that the linear pictograph (and by extension the ceiling sun symbol) refers to the sun near the solstice may be provided by the set of three parallel wavy lines located just above the linear pictograph in Figures 14 and 15. As discussed earlier, such lines represent ongoing or incomplete motion (Martineau 1973:50). Their placement here would then suggest that the linear pictograph refers to the sunrise point on the days before the solstice, and that that point is moving northward during the entire period represented by the pictograph, even though the sun rises in the same place—the bottom of the solstice notch—on the last six days preceding the day of the solstice.

[3] Another symbol possibly related to these two is the pictograph consisting of an ellipse enclosing six parallel wavy lines shown in Figure 12, just to the left of center at the top of the figure. This red-painted symbol was probably seen as circular by its painter and may represent an example of incorporation (Martineau 1973:13) in which elements of different symbols are combined to produce a new meaning. In this case, the symbols for “not moving” or “holding in one place” (a circle with a central dot [Martineau 1973:37]; a possible central dot is, in fact, visible in the center of the ellipse), and for “ongoing” or “uncompleted” motion (wavy lines [Martineau 1973:50]) are combined to state that six things are in ongoing or uncompleted motion but are also staying in one place. Thus, like the wavy lines that accompany the linear pictograph discussed in note 2, above, this symbol can be interpreted as stating that during the six days before the day of the solstice (indicated by the six wavy lines), the sunrise point is still moving northwards even though the sunrise occurs at the same point (the bottom of the solstice notch) each day during that time. Note also that the spacing of the wavy lines decreases by a factor of nearly two in going from the end of the ellipse nearest to the observer (the upper end of the ellipse in Figure 12) to the opposite end, possibly to indicate that the daily motion of the sunrise point is decreasing during the six-day interval.

[4] An example of this type of construction is the 16-rayed sun symbol at Juniper Cave, Lava Beds Natural Monument in northern California (Walker 1985). This

symbol which, from its context, clearly refers to the sun at the summer solstice, also displays a central dot which, according to Martineau (1973:37), indicates "holding" or "staying in one place," a precise description of the sun at the solstice when, for about a week, the sunrise/sunset point shows no detectable motion along the skyline.

[5] Any number of ways might have been chosen to mark the progress of the band of sunlight across the rock surface. As discussed in Section 2, a wavy line indicates ongoing motion. Thus, the zigzag pattern may be a stylized version of the wavy line, utilized to confirm to the reader that the pattern is to be used to measure the advance of the sunlit band.

[6]Note that the best agreement between the times of the appearance of the sun in the cleft and the bisection of the angle between L2 and L3 occurs when the observer at the heelstone lowers his line of sight to the minimum height of 148 cm above ground level, as discussed below.

[7] Note that, similarly to the summer solstice notch at Shelter Rock, the V is produced by the overlapping of various features of the rocks which make up the skyline, as can be seen in Figures 17, 18, and 28. However, these features are at nearly the same distance from the observation point. Thus, small changes in the location of the observer's viewing point—such as the lowering of that point from 163 cm to 148 cm above ground level, as discussed on page 59—have no significant effect on the profile of the V. Note that when the observer, at the heelstone, lowers his eye point from 163 cm to 148 cm above ground level nearly all of the skyline south of the "bottom" of the V is obscured by the north side of Rock 2, as shown in Figure 28. However, the profile of the very "bottom" of the V is not affected this this change.

[8] That the cupule was specifically designed to represent the skyline V is suggested by the following:

(1) The conical shape of this cupule mirrors the straight sides of the skyline V, and differs significantly from that of the other cupules within the main cavity of Rock 3. These other cupules are not conical, but are, instead, approximately parabolic in shape, their profiles closely matching parabolas with focal distances of about 10 mm.

(2) The apex angle of the cupule, measured along the sides of the cone away from the distortion caused by the groove of the descending count line, is $72° \pm 2°$. This value is close to the angle of the lower, linear, portion of the skyline V, which is $76.^\circ9 \pm 1.^\circ5$. (Note that dimensions of the cupule indicated above give an apex angle of about 81°. This larger value results from the fact that the bottom of the cupule, for cross-sectional diameters < 10 mm, is rounded instead of coming to a sharp point.)

[9] Further evidence that this symbol refers to the day count from the sunset at the bottom of the V to the winter solstice may be provided by certain details of the symbol itself:

> First, unlike most other sets of count lines at Shelter Rock and Counsel Rocks, here, as noted, the count lines extend a short distance *across* their connecting bar. Close examination of these extensions suggests that, with the exception of the line at the right-hand (south) end of the set, these features may not be simply extensions of the count lines, but may be small filled circles located close to the connecting bar and perhaps connected to it by fainter, narrower lines. If so, then these features might be small, filled sun symbols, or generalized filled symbols, indicating that the counting is of something distant or going further away and "dark" or "difficult." The line at the right-hand end of the set, on the other hand, does clearly extend across the connecting bar, thus blocking or ending the count.
>
> Secondly, it will be seen that the lengths of the count lines decreases linearly from left to right in the set, again suggesting that the count is of something going further away.

These features may then reaffirm that the pictograph represents the southward motion of the sunset point from the V to its end at the winter solstice.

[10] A somewhat similar winter solstice (sunrise) event occurs at CA–KER–17, on the Kern River, California (Harper-Slaboszewicz and Cooper 1988). Here, during the weeks before the solstice, the sunrise point moves southward along the skyline, arriving at the northern base of a feature called "Peak 4067" approximately three weeks before the winter solstice. The northern slope of this peak parallels the diurnal path of the rising sun. Thus, when the sunrise point reaches the base of the peak, the upper limb of the solar disk skims along the entire northern slope. On the following day, the daily change in $\delta_\odot$ causes a dramatic shift in the location of the sunrise point, which now lies just south of the top of the peak. The sunrise point then slowly, day by day, descends the south slope of the peak until, at the winter solstice, it is located at the bottom of a small V-shaped notch in the skyline near the base of that slope. This shift thus provides a precise means of determining and predicting the date of the winter solstice.

As discussed by Harper-Slaboszewicz and Cooper, the use of this site for observing the winter solstice is suggested by one of the pictographs at the site. This pictograph (shown in their Figure 1) consists of a small, solidly painted circle with $\geqslant 10$ short attached rays, surrounded by three additional sets of radial lines:

(1) An inner set of 15 narrow lines.

(2) A broad intermediate set of 12 rays (or possibly originally 13, based on their spacing).

(3) An outer set of 6 narrow radial lines, interleaved with those of (2), whose outer ends connect to an arc.

This entire configuration is underlain by a long, horizontal wavy line.

The solidly painted circle would appear to be a small sun symbol. As we have seen, the small size indicates a distant sun and/or the sun moving further away, while the solidly painted disk indicates darkness or difficulty. The underlying wavy line indicates ongoing or uncompleted motion. Thus, the pictograph states that it refers to the sun moving southward (going away) and becoming darker (shorter days) and more difficult (colder days), *i.e.*, to the (rising) sun approaching the winter solstice.

The surrounding radial lines may then be related in some way to the day count from the time that the sunrise point first appears just south of the top of Peak 4067 to the winter solstice. Measurement of sunrise positions along the skyline in Harper-Slaboszewicz and Cooper's Figure 4 indicates that at present that interval is 18^{d}, up to and including the day of the solstice. Possibly, the broad lines refer to the initial descent of the sunrise point along the south side of the peak, and the 6 lines connected to the arc to the final days up to and including the day of the solstice.

The 6 lines descending from the arc can be viewed as a set of count lines with an overlying connecting bar, such as are found at Shelter Rock (*e.g.* Figure 6) and Counsel Rocks, but in which the set and the connecting bar have here been bent into the form of an arc. According to Martineau (1973:21, 28), an overlying arc indicates that something is hidden. Here, then, the meaning is that the count of 6, *i.e.* the motion of the sunrise point along the skyline during the 5^{d} before the day of the solstice is "hidden," which is to say "cannot be seen." During this time the motion of the sun in declination is quite small, amounting (at present) to $\Delta\,\delta_{\odot} = 0^{\circ}\,07'$. However, the motion of the sunrise point is even smaller. As indicated above, at the winter solstice, the sunrise point (now) lies at the bottom of a skyline V. Measurements of Harper-Slaboszewicz and Cooper's Figure 4 suggest that once the sunrise point has arrived at the bottom of the V, it will appear to remain there while the solar declination decreases by about another $0^{\circ}\,05'$, so that if the sunrise point reached the bottom of the V 5^{d} before the day of the solstice, it would remain there until the solstice. Between day 7 and day 6 before the solstice, the daily motion is $\Delta\,\delta_{\odot} = -0^{\circ}\,03'$, corresponding to a displacement of the sunrise point of perhaps $\Delta\,\delta_{\odot} = 0^{\circ}\,04'$ along the skyline, which might have still been detectable by the observers. But thereafter the motion, which the pictograph indicates the observers recognized was still occurring, was "hidden" from them—not to be seen—owing to the smallness of that motion and the geometry of the skyline.

Note that if the preceding interpretation of the rays is correct, then if their total number is 19, the age of the pictograph is about 1500 years, while if it is 18, its age is no more than a few hundred years.

[11] That experimentation with projectile points led to the invention of the pointer

is further suggested by the similarity between the apex angles of the pointer and of the small, triangular, side-notched projectile points commonly used throughout the continental United States during the late prehistoric period (approximately the last 1,500 years) (Whittaker 1994). A great many of these points had apex angles close to 30°. As can be seen from Figure 44, the apex angle of the outer half of the pointer is also very close to this value, and may have been copied from that of the projectile points, upon whose shape the concept of the pointer was based.

[12] www.imcce.fr/Equipes/ASD/insola/earth/earth.html

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PART TWO

Ancient Indian Astronomers on the Middle Fork of the American River

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Acknowledgements

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1

Introduction

Two sites that appear to have been used for astronomically related observations are: FS 05–17–54–345 (CA–PLA–797) and FS 05–17–54–346 (CA–PLA–798). These sites were first recorded by W. A. Gortner (1988), who designated them MFM and MFN, respectively. For simplicity, they will be referred to by these Gortner designations throughout this paper. The two sites are located in the valley of the Middle Fork of the American River, in the vicinity of French Meadows; their locations are shown in Figure 1. They are situated on or near the tops of two outcrops of the dark, quartzite bedrock of this region that have been rounded and polished by glacial action. These outcrops rise some 37 m (120 ft) above the surrounding valley floor. This elevation places their tops above the fairly dense vegetation cover of the valley, and gives the observer on their summits a relatively unobstructed view of the surrounding skyline (ridgelines) in all directions.

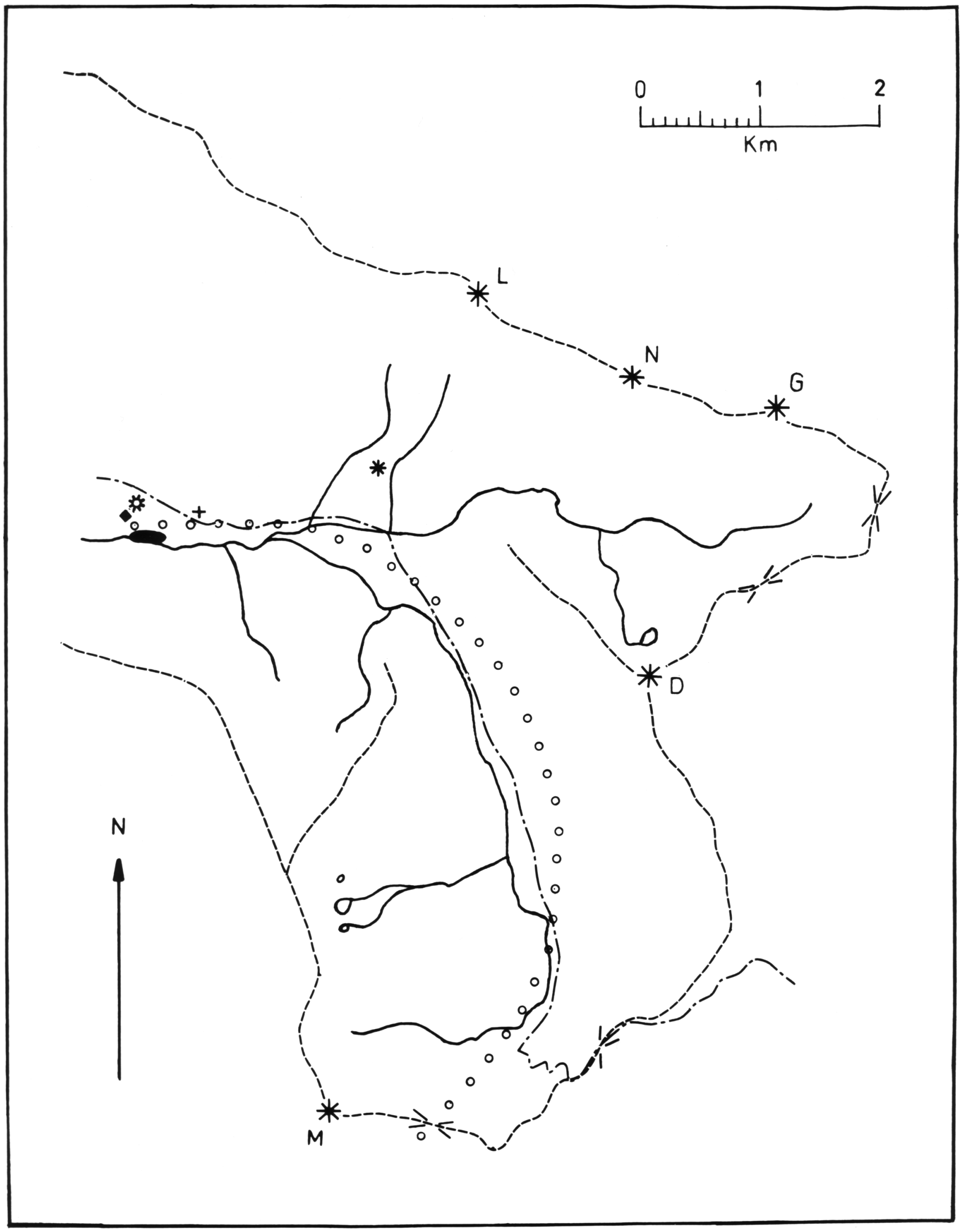

Figure 1. Map of the Middle Fork of the American River and Picayune Creek drainage area. Solid lines indicate rivers and streams; closed loops indicate lakes. Dashed lines indicate ridge lines, while the dot-dash line indicates the present-day hiking and equestrian trail. Ridge-line peaks are indicated by large stars and are identified by letters: L, Lyons Peak; N, Needle Peak; G, Granite Chief; D, Departure Peak; M, Mount Mildred. Passes over the ridge line are indicated by opposing arrowheads on the ridge lines. The smaller star indicates Cathedral Rock. Site FS 05–17–54–345 (MFM) is indicated by the small rayed circle, site FS 05–17–54–346 (MFN) by the diamond, and site FS 05–17–54–416 (Site 416) by the cross. The black area southeast of MFM indicates the large meadow camp site FS 05–17–54–252. The series of open circles shows the curved line inside the "nothing there" symbol at MFM (see Figures 3, 6a, 7a, and 8), adjusted in size to fit the map but retaining its original azimuthal orientation.

2

MFM

Site MFM is the northeastern of the two sites discussed above, and its location is indicated in Figure 1 by the rayed circle. Photographs of the site are reproduced in Figure 2. As these photographs show, the site is located on a horizontal platform of glacially polished bedrock that extends some 6 m east and west and 5 m north and south and is bounded on the west by a drop of 60–90 cm. The site itself is bordered by lines of glacial erratic rocks and boulders arranged along its north, south and east sides. The lines of rocks along the north and south sides of the site are separated by about 1.0 m at their eastern end and by about 2.4 m at the western end of the shorter southern line. The southern line of rocks extends some 2 m east to west and is dominated by three large rocks at its eastern end having dimensions (from east to west) of:

> 70 cm N–S, 30 cm E–W, and 40 cm high;
>
> 65 cm N–S, 20 cm E–W, and 20 cm high;
>
> 60 cm N–S, 40 cm E–W, and 30 cm high.

On the north side, the line of rocks extends about 4.0 m east to west, the largest rock being at the east end and measuring:

> 70 cm N–S, 80 cm E–W, and 60 cm high.

This rock has clearly been in place a long time. A slab some 25 cm thick has spalled off from the east side due to frost wedging and now lies next to the surface from which it came. The cleavage surfaces are obviously quite old, being now weathered and stained and covered with patches of lichen. The western end of the north row is a boulder measuring:

> 55 cm N–S, 100 cm E–W, and 45 cm high.

The area within the lines of rocks retains most of its glacial polish, and into this surface is inscribed the single petroglyph panel located at this site. A rubbing of this panel is reproduced in Figure 3. The situation of the panel on the platform is

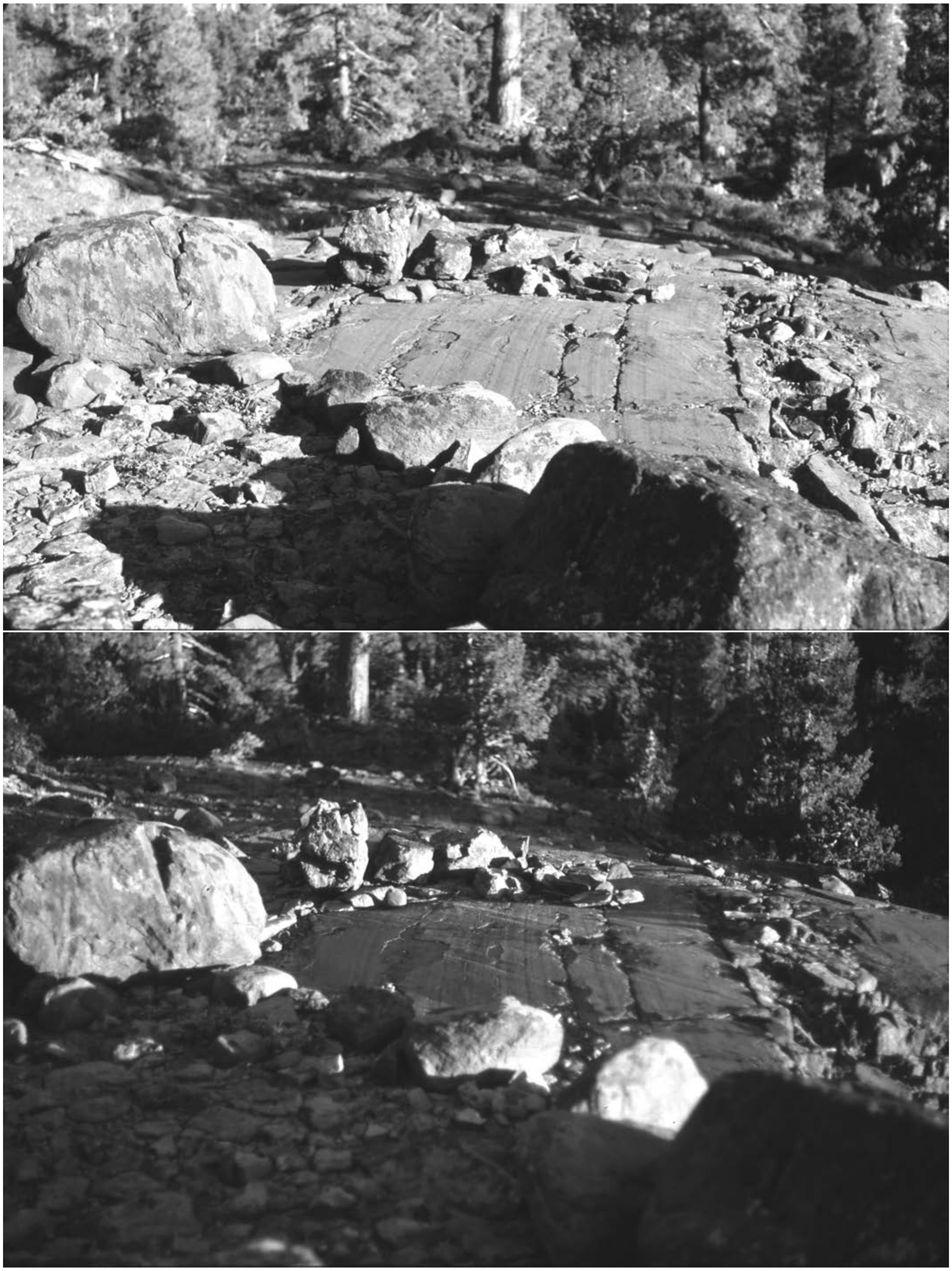

Figure 2. Two views of site MFM as seen from the north with different afternoon sun angles.

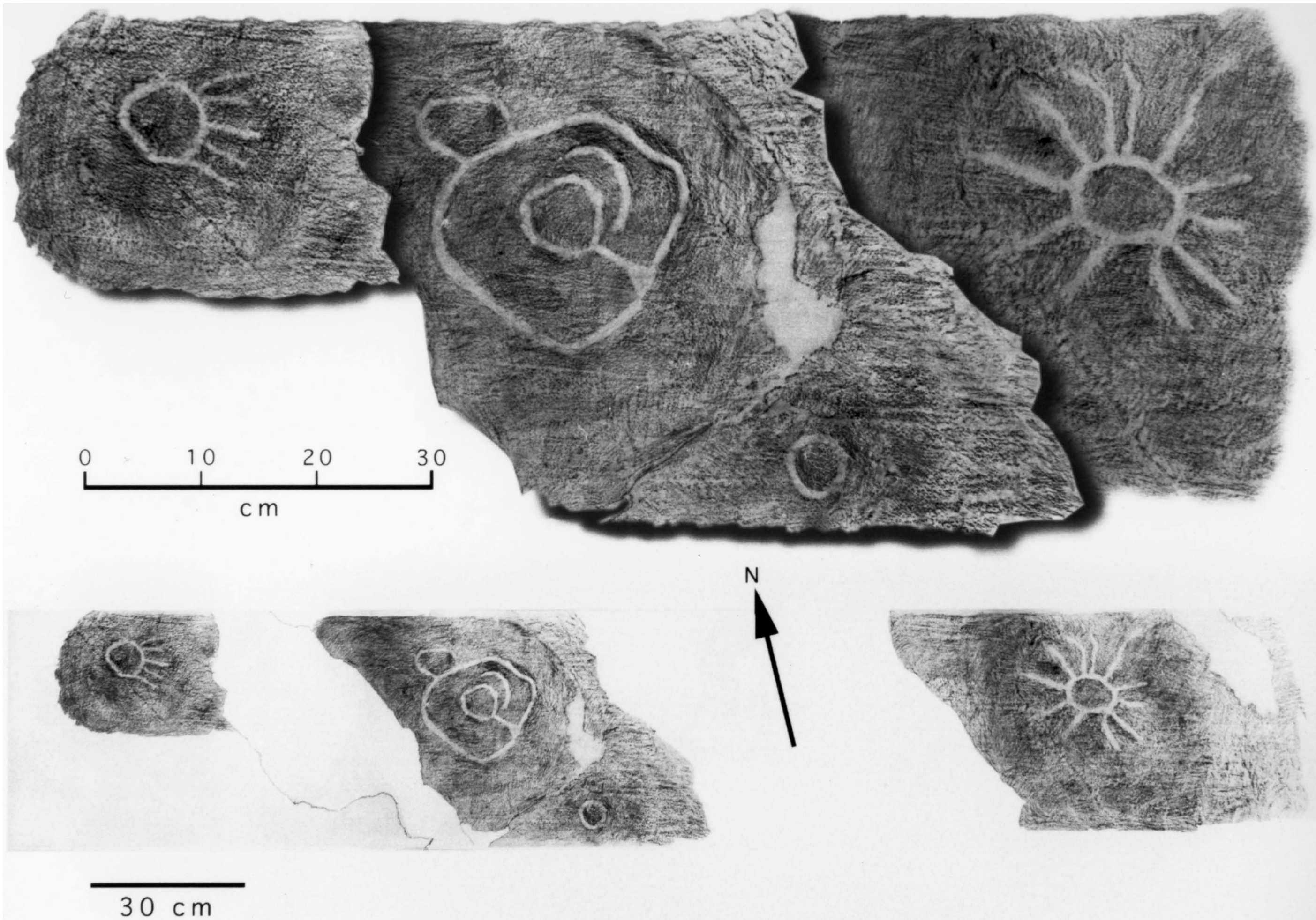

Figure 3. Graphite rubbing of the petroglyph panel at MFM. Only those sections of the rock surface surrounding the west, middle, and eastern petroglyphs have been rubbed. These three sections are shown in their correct relationship to each other in the lower section of the figure. The upper portion of the figure shows enlarged reproductions of these three panel sections brought together along a line through the centers of the eastern- and westernmost petroglyphs.

Figure 4. Top (4a): Site MFM with rocks marking the centers of the petroglyph panel elements shown in Figure 3. View looking southeast. Bottom (4b): Site MFM looking west. Rocks placed on the sun symbol, bear track, and on either side of the center of the central concentric symbol. Tape measure through the centers of the two external circles and the concentric symbol. The distance between the two large boulders in the middle of the photograph is about 1.0 m.

shown in Figures 4a and 4b, where the centers of the east, west and three central elements are marked with rocks. The easternmost symbol lies about 90 cm east of the eastern end of the north- and south-side lines of rocks. The center of the middle of the three central symbols lies some 30 cm west of this point and about 35 cm south of the north-side line of rocks. The westernmost symbol lies some 70 cm still further west, and is about 3.6 m from the western edge of the platform.

The petroglyphs were formed by pecking the surface of the glacially polished quartzite with a sharp rock. The widths of the lines range from about 6–10 mm ($^1/_4$–$^3/_8$ in). Experimentation with a sample of this type of rock demonstrates that this is the width that results naturally from the "striking error" when one tries to make a narrow feature by pecking the rock surface using a piece of quartz as a hammer. Fresh, or recent, pecking on this dark quartzite produces an easily visible, light-colored mark without the need of excavating a groove in the rock surface. Yet, the grooves of the petroglyphs are noticeably deep, indicating that care was taken to produce a mark that would remain visible for a very long time. This was a wise precaution for today there is very little difference in color between the peck marks and the surrounding surface, making the petroglyphs very difficult to see except when illuminated by sunlight striking the rock surface at near grazing incidence, so that the sides and bottoms of the peck marks and grooves are partially in shadow. This is illustrated in Figures 5, 6a, 6b, 7a, 7b and 8, which reproduce photographs of each of the panel elements under low-angle solar illumination.

It is not well established how long it takes a pecked surface to recover the patina of its surroundings, depending as it does on rock type, exposure, and climate. However, it is generally thought that this process requires some hundreds of years. Gortner (1984:10–11) reports that designs pecked into bedrock granite nearly a century ago in a nearby location on the North Fork of the American River so far show no evidence of weathering or patination. We may conclude, therefore, that the petroglyphs at MFM (and indeed all of the petroglyphs in the general area) are quite old.

As indicated above, Figure 3 reproduces a rubbing of the MFM panel. This rubbing was produced by using a graphite pencil on a single long sheet of paper laid out over the panel. The visibility of the petroglyphs was enhanced by erasing all graphite marks within the boundaries of the petroglyph grooves. In the lower portion of the figure, the elements are shown in their correct relationship; note that rubbing was restricted to the areas around each of the panel elements.[1] In the upper part of the figure, the three sections of the rubbing have been brought together along a line passing through the centers of the eastern- and westernmost elements and enlarged in order to show the details of each petroglyph more clearly.

Figure 3 shows that the easternmost symbol of the MFM panel is, basically, a circle with extended rays. This type of symbol is generally accepted as being a sun symbol, suggesting that the site may have had something to do with observing

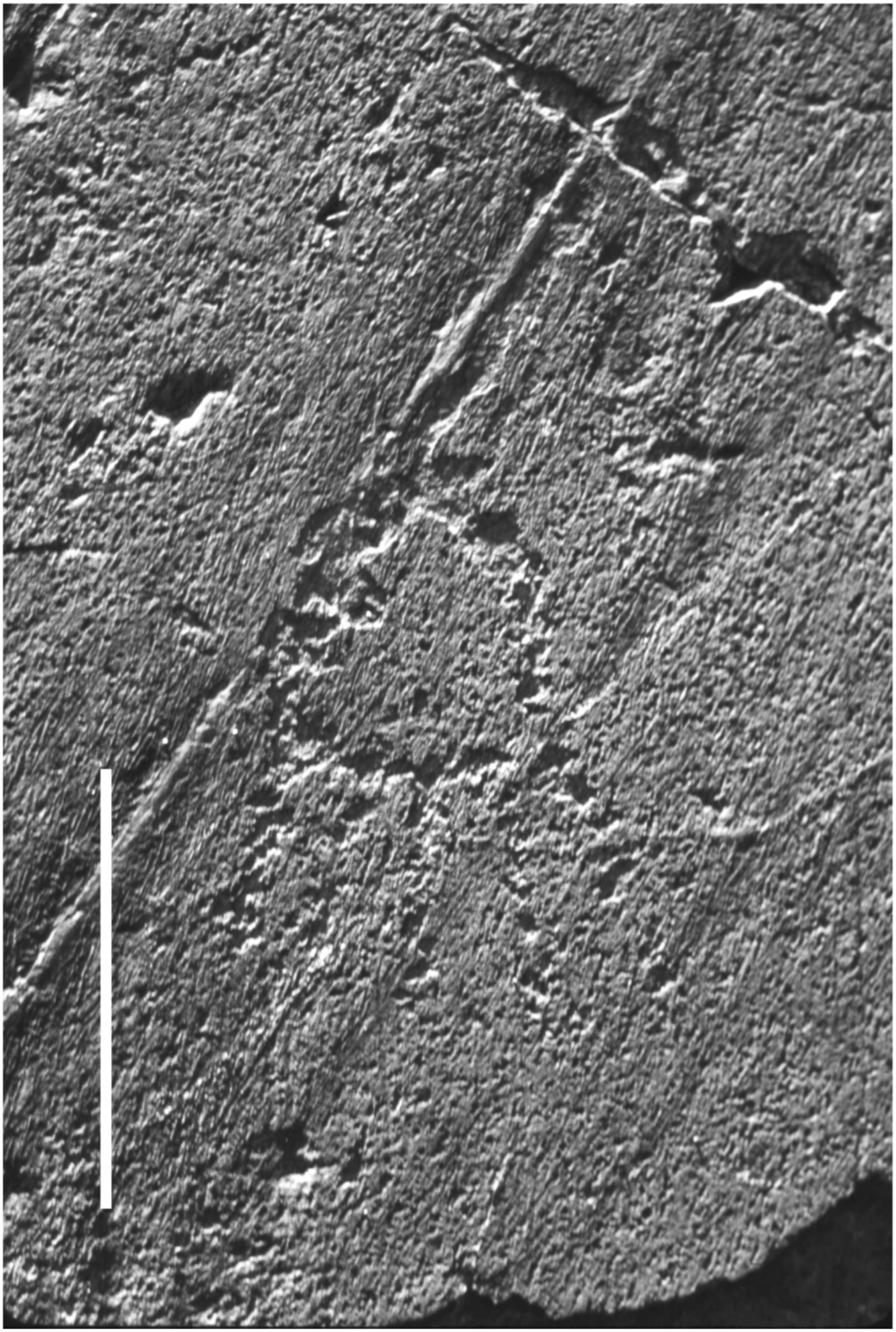

Figure 5. Photograph of the westernmost petroglyph at MFM: the bear track. North at the top. Scale bar = 10.0 cm.

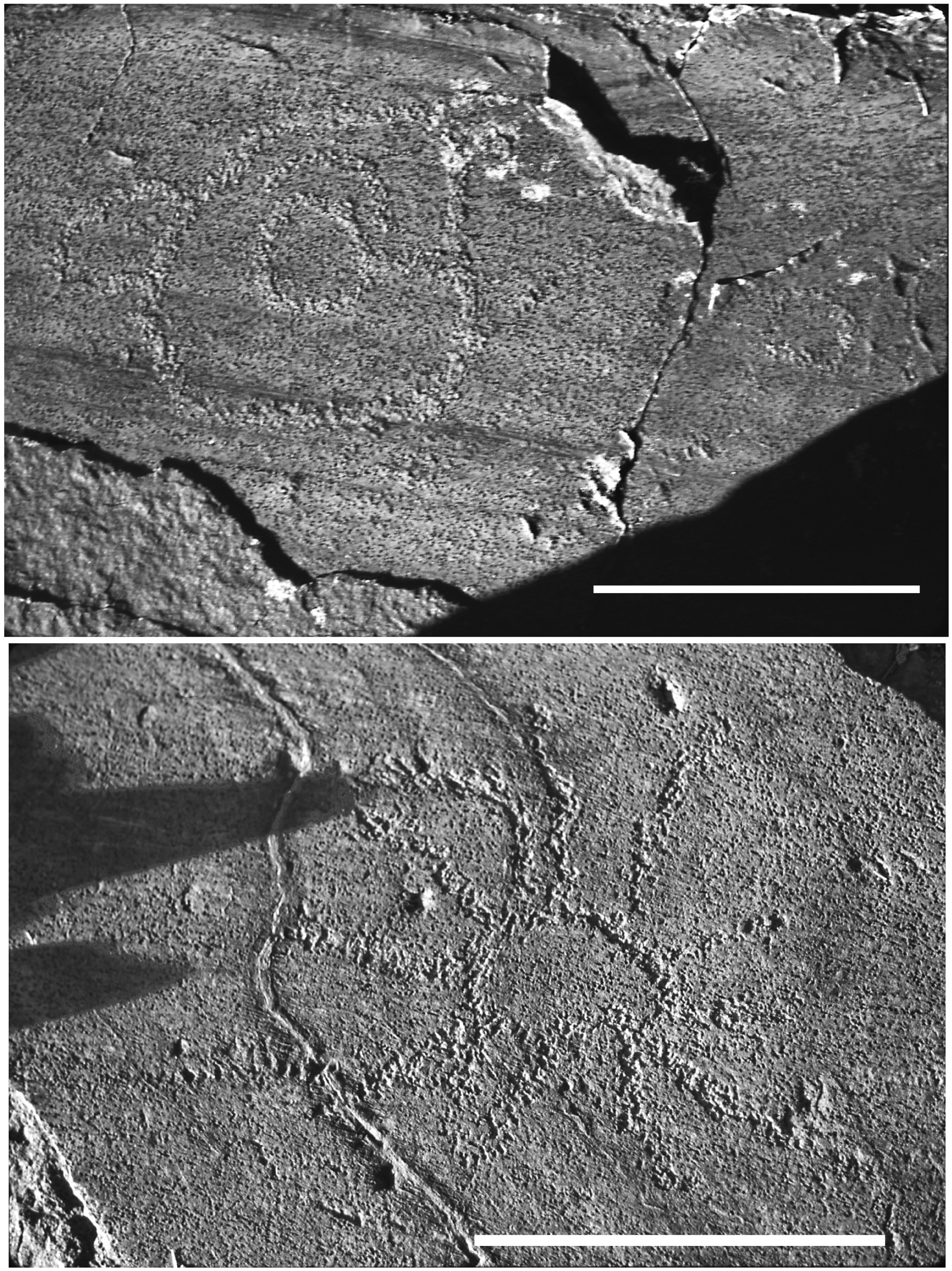

Figure 6. Top (6a): Photograph of the central petroglyphs at site MFM, illuminated by the early morning sun. Northeast at the top. Scale bar = 20.0 cm. Bottom (6b): Photograph of the easternmost petroglyph at MFM: the sun symbol, illuminated by the late afternoon sun. North at the top. Scale bar = 20.0 cm.

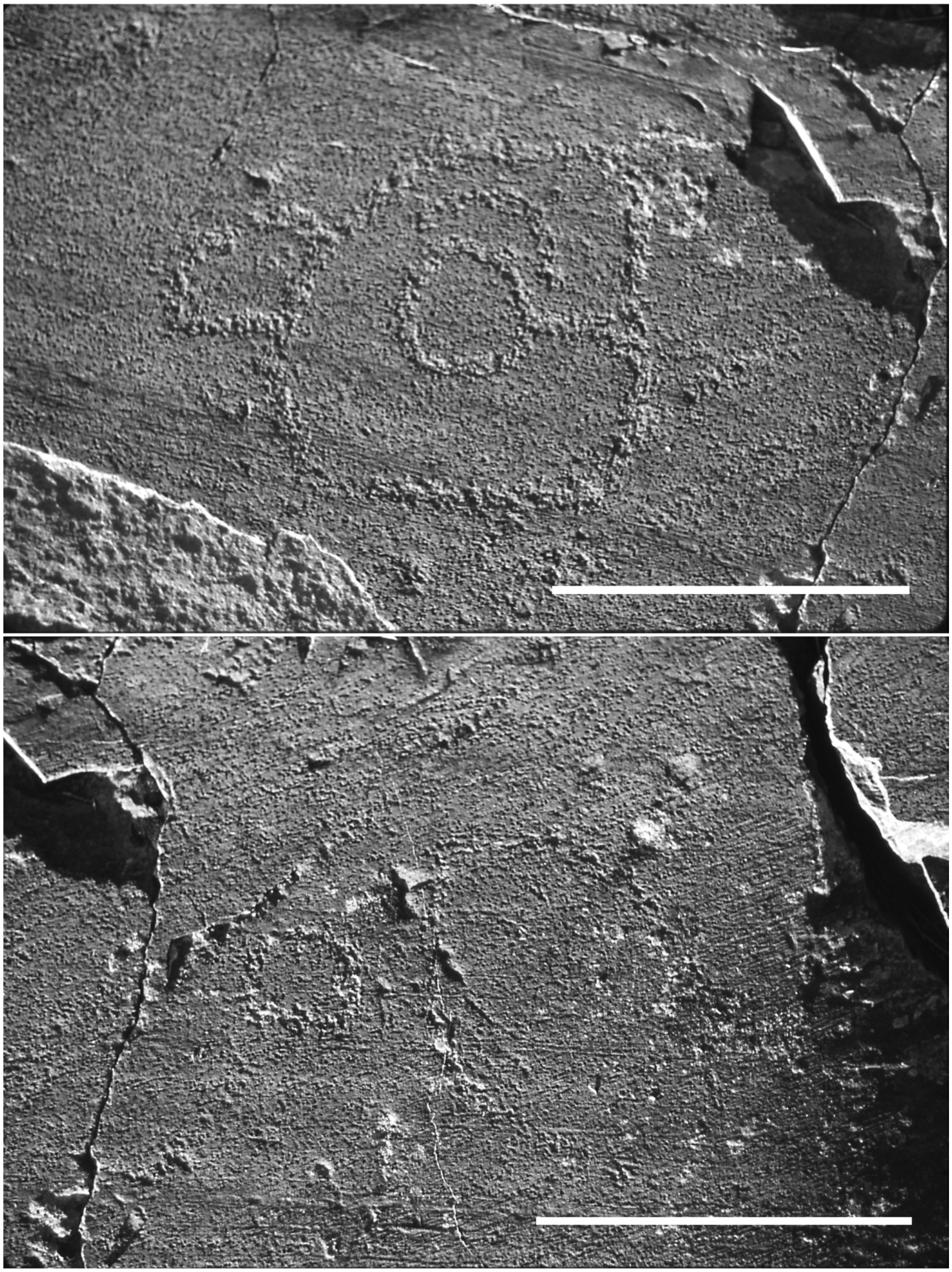

Figure 7. Top (7a): Large-scale photograph of the central petroglyphs of the panel at MFM, as illuminated by the late afternoon sun. Northeast at the top. Scale bar = 20.0 cm. Bottom (7b): Photograph of the rock surface at MFM to the right of the area shown in Figure 7a, illuminated by the late afternoon sun. Northeast at the top. The detatched exterior circle of the central petroglyphs is located to the left of center in this photograph. A second feature noted by Gortner is situated to the right of center, but appears to be a natural marking. Scale bar = 20.0 cm.

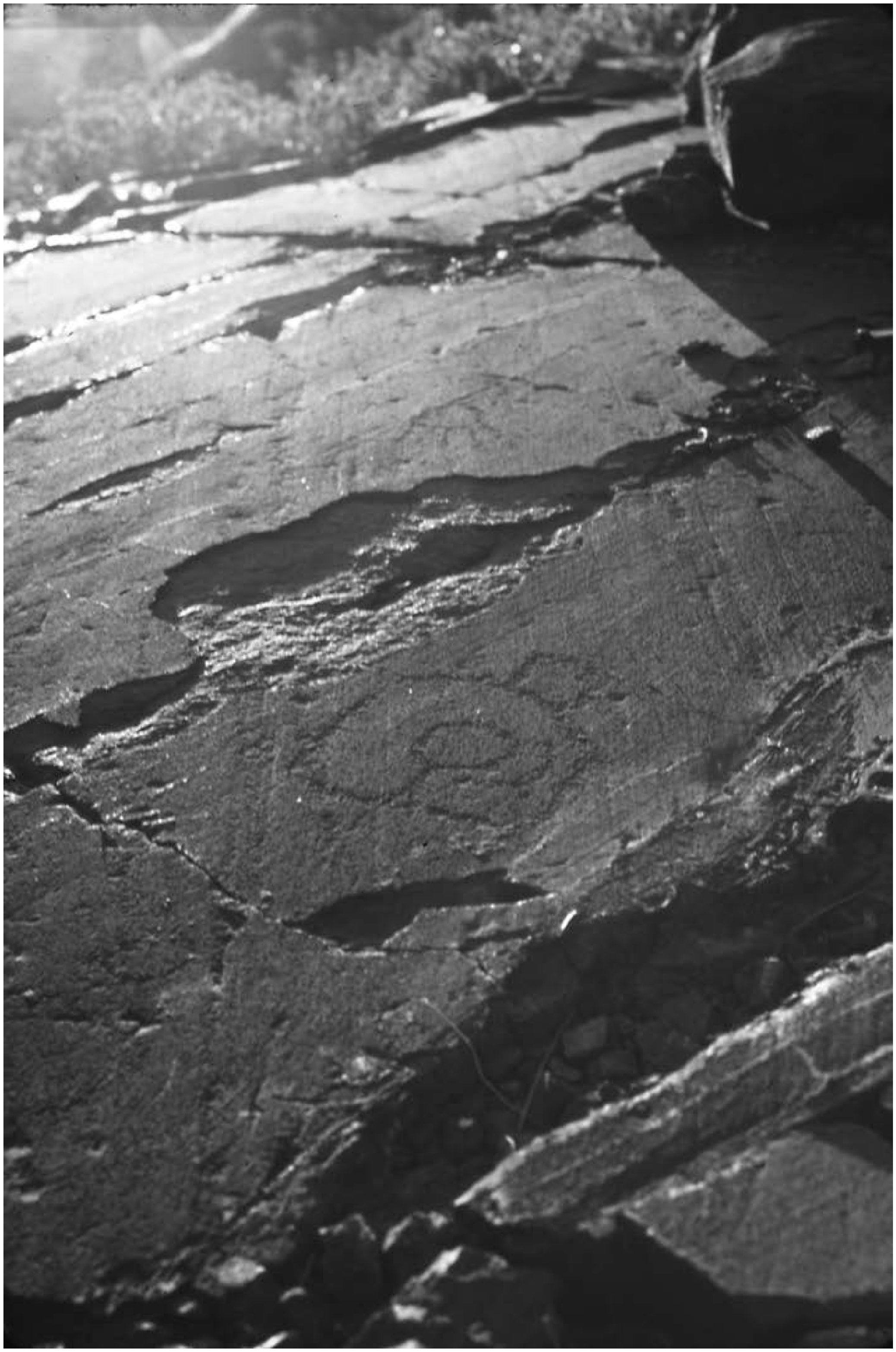

Figure 8. Photograph of the glacially polished rock surface at site MFM, looking westward with low afternoon sun. The central portion of the petroglyph panel is visible near the center of the figure, while the westernmost symbol—the bear track—is located about midway between the central symbols and the top of the figure.

the sun. The westernmost symbol appears to be that of the track of the forepaw of a bear. The Bear Spirit is still today highly venerated by the Indians as a source of help and guidance in their lives, and in some tribes is celebrated by a Bear Dance held near the time of the summer solstice. It would seem possible, therefore, that the Bear Spirit was similarly regarded in earlier times. The bear track could thus be interpreted as being a reference point from which observations were to be made, analogous to the "eye" symbol ($\triangleleft$) used in published diagrams of optical systems to indicate where the observer's eye is to be placed, and the direction in which it should look. Thus, the Bear Spirit, our guide, directs us to stand where the Bear stood (on the forepaw track) and to look in the direction the bear looked: toward the sun symbol. We are, in other words, directed to look at the sun in the direction of the sun symbol, which is to say the sun rising over the eastern skyline (some 10° above the true horizon). Directing our gaze along the projection of a line through the bear track and the sun symbol, we find that this projected line does in fact intersect an isolated, triangular-shaped peak on the skyline, shown in Figures 9 and 10.

That the bear track was intended as the viewing point is further suggested by the shape of the sun symbol itself. As shown in Figures 3 and 6b, this symbol does not actually consist of a circle with straight, radial rays as in the usual sun symbols. Instead, the "circle" is an ellipse, with its long axis pointing toward the bear track, and the rays on the north side of the symbol are not straight but have ends that bend towards the east or the west, depending on whether the ray is located east or west of the center of the ellipse. Let us consider first the ellipse. As indicated in Part One, a perfectly circular symbol was one of the easiest shapes to construct. Thus, departures from circularity were very likely intentional. The inscriber of the sun symbol, then, deliberately produced an elliptical figure rather than a circular one.

As discussed in Part One and in the next section, an ellipse having major and minor axes a and b, respectively, will appear circular when viewed from the direction of the major axis at an angle, α, above the plane of the ellipse such that $\sin\alpha = {}^{b}\!/_{a}$. By viewing the rubbing of the sun symbol from the direction of the bear track at various angles above the plane of the symbol, we find that the ellipse appears, overall, most nearly circular in shape when $\alpha = 38^\circ \pm 1^\circ$. This angle was determined by averaging the angles at which, just detectably, $a > b$ and $b > a$. Note that the uncertainties given here and throughout this paper are the standard deviations (σ). At the bear track, this angle corresponds to a height of 147 cm ±5 cm (58 in ±2 in) above the platform surface. Allowing 10 cm (4 in) for the distance from eye level to the top of the observer's head when looking downward at the sun symbol, this result suggests that the petroglyph was designed to appear circular to an observer standing at the bear track and having a height of about 157 cm (62 in, or 5 ft 2 in).[2]

Apparently, no studies have been made of the heights of the prehistoric Indians of this region. A study of the heights of *living* Indians was published by

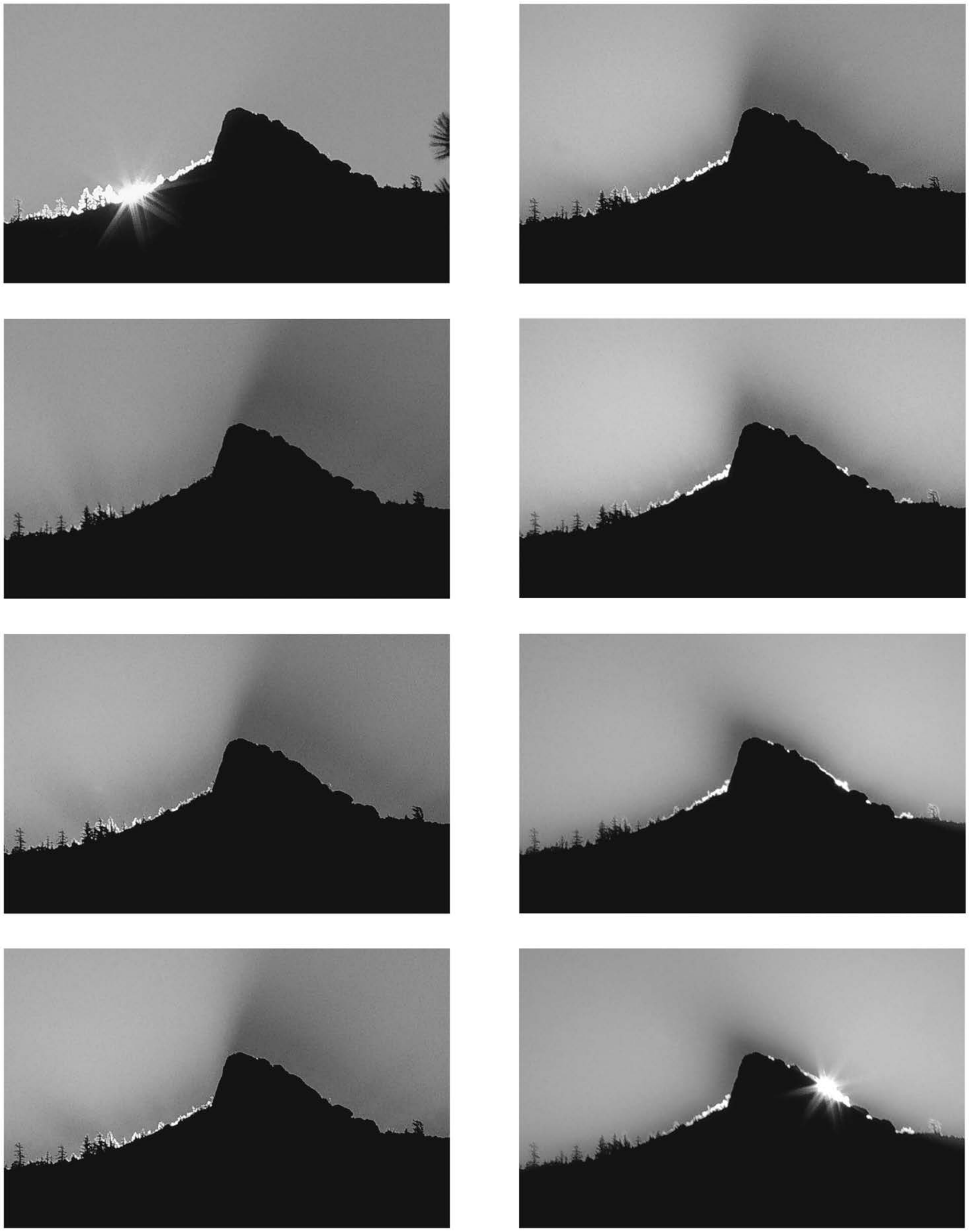

Figure 9. Alignment Day sunrise viewed from MFM. (Top to bottom, left to right): (a): 1999 October 12, 07:03:24 PST. All other photographs taken 1999 October 13, at the following PST times: (b): 07:01:14; (c): 07:02:44; (d): 07:03:14; (e): 07:04:07; (f): 07:05:14; (g): 07:06:02; (h): 07:06:07. All photographs on Kodachrome 25, 210 mm focal-length lens, exposure 1/60 sec at f/11. Note the shadow of Departure Peak in the sky above the peak on October 13, resulting from forest fire smoke in the atmosphere above the peak.

Table 1. Heights of Indian Men 19–60 Years of Age.

Tribe	Number Measured	Average Height (cm)	σ (cm)
Washo	6	173	—
Southern Maidu	1	162	—
Hill Maidu	22	163	6.8

Gifford (1926:217–280), based on data collected during the twenty or so years preceding that publication. According to Gortner (1986:27), the descendents of the prehistoric Martis Complex Indians, thought to have been the original inhabitants of the region, might be the Washo, but could also be the Nisenan or Southern Maidu (and especially the "Hill Nisenan") Indians. For these groups, the heights of men aged 19 to 60 years published by Gifford (1926) are given in Table 1. Unfortunately, the number of individuals measured in any one tribe was usually very small, which precludes any statistical generalizations from the observations. These heights are slightly greater than the value derived from the panel. However, for the Maidu that difference is less than the standard deviations of both the panel value and of the largest set (the Hill Maidu) reported by Gifford. Furthermore, a slightly smaller height might be expected among the prehistoric Indians due to poorer diet; the individuals included in the Gifford study may have been slightly taller than earlier generations owing to dietary changes resulting from the advent of the Europeans about 1850. Thus it would appear, from what little evidence is available, that the height of the author of the MFM petroglyphs inferred from the panel is at least plausible.

It is certain from the examples discussed in Part One that at least a few other Indian rock writers did inscribe or paint ellipses on the rock surface in such a way that those symbols appear circular when seen from the writer's or observer's position. The petroglyph panel, then, directs the reader to observe the sun rising in alignment with the triangular peak on the eastern skyline. But why? What is the significance of this sunrise?

The altitude of the base of the peak (on its southern side) is $h = 10°00'$, and the top is $h = 10°24'$, measured with a surveyor's transit. The sun rises in alignment with the peak on October 12 or 13 in the fall (shifting by one day due to the effect of leap year) and on March 1 in the spring. Whatever its significance, the "Alignment Day" sunrise is a spectacular event. When the solar declination has just the right value, as on October 12, 1998, when the solar declination at sunrise was $\delta_\odot = -07°28\overset{'}{.}3$, the upper limb of the sun first appears at the left-hand base of the peak. In 1998, this occurred at $07^{\mathrm{h}}\ 04^{\mathrm{m}}\ 10^{\mathrm{s}}$ PST. The limb then moves upward along the north side of the peak until, at $07^{\mathrm{h}}\ 06^{\mathrm{m}}\ 25^{\mathrm{s}}$ (in 1998), the limb also emerges above and to the right of the top of the peak, forming an intense halo of light around the top of the peak. This appearance lasts only a few seconds, and then all is lost in the blinding glare of the emerging solar disk.

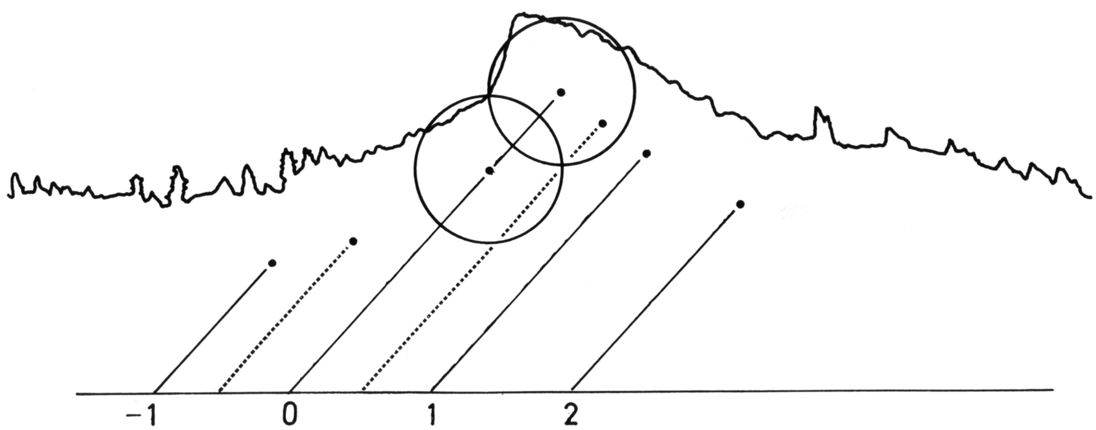

Figure 10. Geometry of the Alignment Day sunrise. Departure Peak and adjacent skyline traced from a photograph taken at MFM. The horizontal line is an arbitrary level line. The inclined solid lines indicate the path of the center of the solar disk on successive days, day zero being 1998 October 12, when $\delta_\odot = -07°28'.3$ at sunrise. The circles indicate the solar disk, $32'$ in diameter, and the dots at the ends of the inclined lines show the position of the center of the solar disk when the upper limb first appears above the skyline. The dotted lines indicate the range of the variation in the path of the sun due to leap year.

The geometry of the Alignment Day sunrise is shown in Figure 10. This figure shows the outline of the peak, traced from a photograph, together with the size, position and direction of motion of the solar disk. The circles indicate the solar disk, $32'$ in diameter, and the solid inclined lines show the path of the center of the disk on successive days, day zero being October 12, 1998. The dotted lines indicate the maximum extent of the year-to-year variation in the position of the day zero path in the four-year leap-year cycle, resulting from the fact that the length of the year is not an integral number of days. Dots indicate the position of the center of the solar disk when its upper limb first emerges above the skyline, and when the emerging limb forms a symmetric halo around the summit of the peak. The horizontal line represents an arbitrary level line.

Even in those years when the edge of the solar disk does not project beyond the north side of the peak, the sunrise is still spectacular. This is illustrated in Figure 9, which shows photographs of the sunrises on October 12 and 13, 1999. The photograph at the upper left of the figure shows the sunrise on October 12, and was taken at $07^{\rm h}\ 03^{\rm m}\ 24^{\rm s}$ PST. The other photographs show (top to bottom and left to right) successive views of the sunrise on October 13, and cover the interval from $07^{\rm h}\ 01^{\rm m}\ 14^{\rm s}$ to $07^{\rm h}\ 06^{\rm m}\ 07^{\rm s}$ PST. The solar declination during the observations on October 13 was $\delta_\odot = -07°45'.3$. Even though the solar limb does not appear until $07^{\rm h}\ 06^{\rm m}$ PST, the peak is illuminated by a rim of light which first appears on the north side of the peak at its base and then intensifies and moves part way up the north side of the peak. Then, points of light begin to appear near the top and along the south side of the peak, so that the entire peak is outlined in light. This illumination results from sunlight scattered by the vegetation growing on the peak. Finally, the solar limb emerges near the middle of the south slope of the peak, and within a few seconds the entire spectacle disappears in the increasing glare of the solar disk. Note, on the photographs taken on October 13, the shadow of the peak projected into the air above the peak. This appearance resulted from forest fire smoke in the atmosphere above the peak.

So, the Alignment Day sunrise is a spectacular event and was, apparently, marked by ceremonies at MFM. That at least several observers were present to view the Alignment Day sunrise is suggested by the placement of two rocks just north of the petroglyph site. These rocks, shown in Figures 11, 12a and 12b, are located 4 m north of the line of rocks that form the northern boundary of the site, and sit on the top of a bedrock outcrop that is 55 cm higher than the surface of the platform on which the petroglyphs are inscribed. The two rocks are 32–35 cm high, 80–90 cm long, and 22–28 cm wide. The two have clearly been, at some time in the distant past, split from a single rock. The cleavage faces are the present north side of the eastern rock and the present top side of the western rock. There is no clear evidence as to how the eastern rock may have been moved. However, it is certain that the western rock has been moved at least twice. If the position of the eastern rock had remained unchanged, then after splitting from the eastern rock, the western rock would have had to lie immediately north of the east rock. The slope of the ground rules out natural migration of the west rock from that location to its present position west of the east rock. Further, the top face of the west rock, which cleaved from the north face of the east rock, is relatively unweathered, whereas all other surfaces of the west rock (including the present bottom side) as well as all four sides and the top of the east rock, are highly weathered.

Clearly, then, the west rock, at least, was removed from its original location next to the east rock—wherever the east rock may then have been—and, after lying with its cleavage face down for a very long time, was then turned over to place the cleavage face on top. This is illustrated in Figures 12a and 12b, which show the two rocks as seen looking north from the petroglyph site. Figure 12a (top) shows the rocks as they were found, the west rock having its unweathered cleavage face uppermost. Figure 12b (bottom) shows the west rock turned over to show the weathered surface of what is now the bottom side of this rock.

The size, shape and location of these two rocks, together with the fact that at least one of them has been moved, suggests that both of them may have been placed in or near their present locations to provide two observing benches facing toward the petroglyph platform. Two other possible viewing seats are located some 3 m west of the two rocks just discussed. These rocks have dimensions of:

height 35 cm, length 40 cm (E–W), width 20–40 cm (N–S);

height 50 cm, length 60 cm (E–W), width 50 cm (N–S).

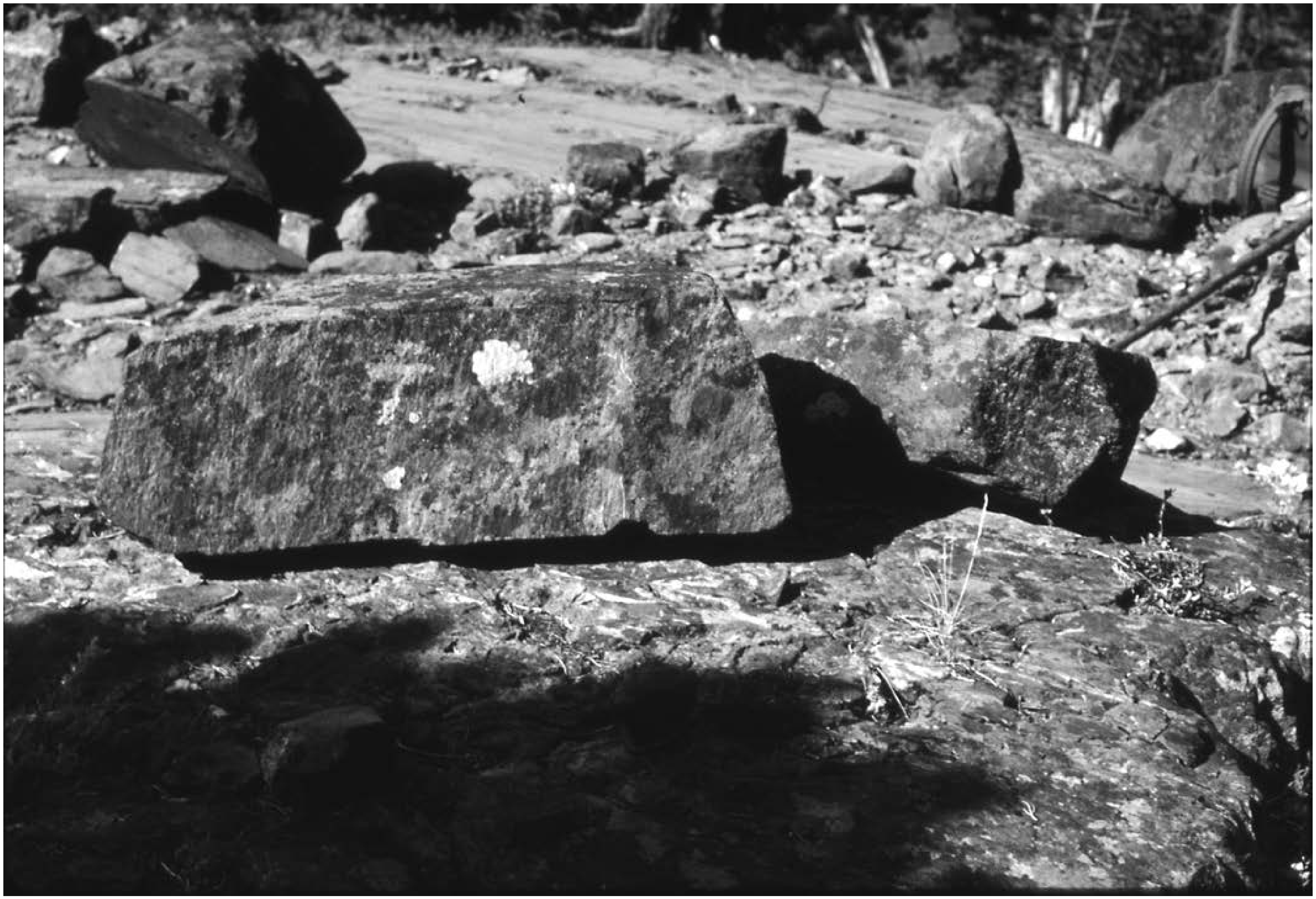

Figure 11. Viewing seat rocks at MFM, looking south. The eastern of the two rocks is about 85 cm long and 32 cm high. See text.

But what, apart from its spectacular appearance, was important about this particular sunrise, or this particular date? The dates of the Alignment Day sunrise—March 1 and October 12 or 13—do not correspond to any special point in the yearly motion of the sun, such as the equinox or the solstice. In fact, only the fall alignment would have been observable; the region is typically under one or two meters of snow on March 1. That the autumn alignment was being observed appears to be confirmed by the sun symbol itself. As discussed above, Figures 3 and 6b show that the rays on the north side of the symbol are not straight, but have ends that are bent towards the east or the west depending on whether the ray is located east or west of the center of the symbol. This shape suggests an attempt to indicate motion of the sunrise point southward along the skyline. These rays may, in fact, incorporate the symbol for "missed" (Martineau 1973:18–19), which consists of a straight line with a bent top section, indicating that in the direction of the rays (north), the sun is "missing" because the sunrise point is moving southward along the skyline. Thus, we are being directed to observe the sun in alignment with the triangular peak in the fall as it moves southward along the skyline. But why?

We begin by noting that the valley of the Middle Fork, where sites MFM and MFN are located, was occupied only during the summer months. This is shown by the archaeological studies. These studies demonstrate that the Martis winter camps were located at elevations below about 1200 m (4000 ft) (Elsasser 1960:26), while the valley of the Middle Fork has, in the vicinity of MFN and MFN, an elevation of 1840 m (6000 ft) or higher. Additionally, winter encampments are characterized by well-developed midden deposits (Elsasser 1960:72–73); such deposits are not found at campsites in the region considered here (Gortner 1988).

Clearly, if one were living in a summer camp high in the Sierras, one of the primary concerns would be to determine when to leave the area in order to avoid being trapped by the first severe autumnal storm. The alignment of the rising sun with the triangular peak might have been used for this purpose, and this supposition appears to be confirmed by the petroglyph panel itself.

Referring to Figure 3, let us now consider the symbols in the middle section of the panel. These consist of a set of two concentric circles, the outer one being somewhat misshapen, and two exterior circles, one tangent to the outer of the two concentric circles and the second situated at some distance from the others. Drawing a straight line from the center of the bear track to the center of the sun symbol, we see that this line crosses the center symbol in such a way that the northern exterior circle is tangent to it and the outer of the two concentric circles overlaps it only slightly. Further, the centers of the two external circles and of the inner concentric circle lie very closely along a straight line, suggesting that these symbols are all related to each other in some way.

The symbol consisting of the two concentric circles has been translated by Martineau (1973:152) and has the meaning of "empty" or "nothing there." Martineau (1973:35) points out that Indian pictographic writing employs the principles of

Figure 12. Viewing seat rocks at MFM, looking north. Top (12a): Rocks in original position, with unweathered cleavage face of west rock uppermost. Bottom (12b): West rock turned over to show weathered surface of bottom side of the rock. See text.

incorporation and extension, i.e., the combination of different elements into a single ideograph, which modifies the basic symbol so as to change or elaborate its meaning. The basic "empty" concentric-circle symbol in the MFM panel contains three such incorporations:

(1) As indicated earlier, the outer circle of the symbol appears at first glance simply to be rather poorly drawn and irregular. However, closer inspection reveals that it is, in fact, not a circle at all but is, actually, a square with rounded corners, one corner being cut off (approximately) by the line through the bear track and sun symbols. This fact becomes readily apparent if one covers up the cut-off corner of the symbol in Figure 3, 6a or 7a. Martineau (1973:152) translates the symbols of a square or a rectangle as meaning a place or an area. At MFM, the outer of the two concentric circles has been modified to have straight sides, while still retaining its overall circular form, in order to indicate that what is "empty" is a specific place or area.

(2) The inner and outer circles are connected by a line which is located at the midpoint of one of the complete sides of the square. According to Martineau (1973:100–101), a radial line in a concentric-circle symbol indicates "gone." Thus, the line in the present petroglyph modifies the basic symbol to say that the area or place is "empty" because what was in it has "gone" out. Note that the outer end of this line, where it joins the outer "circle," has been deliberately widened. This can be seen clearly in Figures 6a and 7a, where the individual peck marks are easily visible. A broad line indicates a bad trail (Martineau 1973:90). Thus, the widening of the line—representing the trail by which "that which was here" (the people) left—indicates that this trail becomes bad or difficult just when leaving the area, as is in fact the case, as discussed below.

(3) Figures 3, 6a, 7a and 8 show that there is also, included between the inner and outer circles, a curved line segment, whose north end lies on the line joining the bear track and sun symbols. This feature, adjusted in scale but preserving its original azimuthal orientation, has been plotted on the map in Figure 1, where it is shown by a series of open circles. This map shows the valley of the Middle Fork of the American River from the petroglyph sites, MFM and MFN, eastward to the crest of the Sierras. Rivers, streams, and lakes are indicated by solid lines, while ridge lines are shown by dashed lines, and passes over the ridge lines are indicated by opposing arrowheads. Peaks along the ridge lines are indicated by large stars and identified by letters; the names

> of the peaks are given in the figure caption. The present-day trail up the Middle Fork and across the ridge line to the eastern slope of the Sierras is shown by the dash-dot line. The Middle Fork runs directly eastwards to its headwaters just below the Sierra crest. Picayune Creek flows northward through Picayune Valley and joins the Middle Fork at a point about half way between the center and the left-hand edge of the map.

It will be seen that the projection of the petroglyph onto the map matches very closely both the course of the Middle Fork and Picayune Creek and the present-day trail. This trail is used both by hikers and equestrians and presumably represents the easiest route from the floor of the Middle Fork valley across the crest to the eastern slopes of the Sierras. It is likely, therefore, that the Indians used the same route. A route up the Middle Fork to its source and then on over the pass directly above would clearly be much shorter. However, the terrain above the point where the present trail leaves the Middle Fork and proceeds up Picayune Valley is so difficult as to make this route virtually impassable; the present route is vastly superior even though it is considerably longer. That the present trail approximates the route followed by the Indians is further suggested by the fact that, eastward from MFM, the Indian campsites that have so far been located (petroglyph and lithic-scatter sites) also all follow closely along the courses of both the Middle Fork and Picayune Creek, and of the present-day trail. These sites extend up Picayune Creek to just below the point where the present-day trail leaves the Picayune Valley floor and switchbacks up to and over the ridge enroute to the eastern slope; none have been found in the upper reaches of the Middle Fork above the junction with Picayune Creek. Note that this trail matches the description given in the panel: it becomes difficult just when leaving the valley by the steep switchback up to the pass.

The agreement of the petroglyph with the shape of the Middle Fork and Picayune Creek watercourses, the present-day trail, and the distribution of the known Indian sites strongly suggests that this line was included within the "nothing there" symbol either as a map of the region (or "property") referred to by that symbol, or as a trail map showing the route taken by the people in leaving the area. In order to determine which of these two possibilities is the more likely, we next examine the orientation of the "nothing there" and "going out" symbols.

Measurements on the topographic map of the region indicate that the azimuth of the pass traversed by the present trail as seen from MFM is $A = 140\overset{\circ}{.}3 \pm \overset{\circ}{.}4$, and the azimuth difference between the triangular peak indicated by the petroglyph panel (which, in view of the preceding discussion, will hereafter be referred to as "Departure Peak") and this pass is $\Delta A = 30\overset{\circ}{.}8 \pm \overset{\circ}{.}1$, the uncertainties being in both cases derived from repeat measures of these angles on the map. The azimuth of the "going out" line is difficult to measure with high accuracy owing to the fact that it is very short and that it becomes wider at its outer end. However, measuring along the axis of this line on the rubbing reproduced in Figure 3, we

Figure 13. Site MFM, looking southeast. Tape through “going out” symbol. See text.

obtain an azimuth difference between the line through the centers of the bear track and the sun symbol and the “going out” line of $\Delta A = 29^\circ\!.0 \pm^\circ\!.4$, based on repeat measures. Since the “going out” line appears to be centered in one side of the squared outer circle of the “nothing there” symbol, we might suppose that this line was intended to be parallel to the northern and southern sides of this square. If so, then the longer sides of the square may give a better determination of the azimuth of the line (and the square). Measuring the rubbing, we find for the north side of the square $\Delta A = 30^\circ\!.8 \pm^\circ\!.3$, for the south side $\Delta A = 32^\circ\!.4 \pm^\circ\!.2$, and averaging, $\Delta A = 31^\circ\!.6 \pm 1^\circ\!.0$. These values are very close to the azimuth difference of $\Delta A = 30^\circ\!.8$ measured on the topographic map, suggesting that the orientation of the “going out” line was indeed intended to indicate the direction in which the exodus occurred.

The question then arises: how could the “going out” line and the sides of the square have been oriented towards the pass with an accuracy of about $\pm 1^\circ$? Figures 13 and 14 show the view towards the southeast from MFM, with a tape measure lying along the axis of the “going out” line, and illustrate the fact that the view of the pass is obstructed by an intervening ridge, as shown in Figure 1. It would, however, be quite easy to establish the direction of the pass with an accuracy of better than $\pm^\circ\!.5$. To do this, one first selects a reference mark at MFM. Note in Figures 13 and 14 that the “nothing there” symbol is located just northwest of, and the “going out” line points directly towards the largest, easternmost rock of the line of rocks along the south side of the MFM platform. Thus, this rock could have served as the reference mark, being made visible from a distance by being painted, covered with a light-colored skin, or having a signal fire built on or just southeast of it. A survey party is then sent up onto the intervening ridge. Using a long, straight pole, observers at either end sight first along the pole to the pass and then, from the opposite end of the pole, towards the marker at MFM. The survey party then moves along the ridge until they locate that point at which the southeast end of the pole points to the pass when the northwest end points to the marker at MFM. At this point, a marker is set up on the ridge, or a signal fire started. Back at MFM, the observer there now stretches a cord from the reference rock and aligns it to the direction of the marker on the ridge. Holding it in this position, an assistant then uses a plumb line to transfer this direction line to the platform surface below. The petroglyphs are then pecked in along lines drawn parallel to this reference line. The use of this procedure may explain the positioning of the “nothing there” symbol in the panel; it would clearly have been the most convenient to locate this symbol directly behind the reference rock. The procedure just outlined automatically placed the petroglyph there; more effort would have been required to locate it somewhere else.

If the azimuth of the “going out” line does indicate the direction in which the going out occurred, then it would appear that the curved line within the “nothing there” symbol is more likely to be a map of the area being left than

Figure 14. Site MFM, looking southeast. Tape through "going out" symbol. See text.

a trail map, since there would be no need to repeat information on going out. This interpretation is also more in accord with the shape of the line. As Figure 1 shows, when scaled to match the curve of the water-courses and the trail from MFM up into Picayune Valley, the southern end of the line extends all the way up to the head of the valley, well beyond the point where the trail zigzags up to the pass.

To summarize, the central portion of the MFM petroglyph panel tells us that the area shown by the map and comprising the Middle Fork and Picayune Valleys is "empty" because what was in it (the people) have "gone" out in the indicated direction. However, there remain two more elements in the central section of the panel: the two exterior circles.

It is generally accepted that a crescent or a circle without exterior rays represents the moon. What could be the significance of two moon symbols in the context of the MFM panel? As noted earlier, the fact that the centers of the two circles and the "nothing there" symbol lie precisely along a straight line suggests that the writer of the panel is telling us that all three symbols are related to each other in some way.

Knowledge of the length of the lunar period (the synodic period, the interval between the same lunar phase as from Full Moon to Full Moon, $29^{\mathrm{d}}.53$), was widespread among ancient peoples, perhaps as far back as the paleolithic era which extended from about 50,000 or 30,000 to about 12,000 B.C. (Brown 1976:9–38). The lunar month was the only available measure of time for intervals longer than a day and less than a year, and the use of the moon was one of the earliest forms of time keeping (Brown 1976:9–38). Lunar calendars are known to have been used by certain tribes of American Indians (Brown 1976:9–38), so it appears likely that the lunar period would have been known and used by the writer of the MFM panel.

The two moon symbols might thus be intended to indicate an interval of one lunation or lunar month. Since, as indicated above, the moon and "nothing there" symbols are related, the location of the north moon, with its south side tangent to the line through the bear track and sun symbol, would suggest that the panel is indicating that "nothing there" occurs some fraction of a lunation after Alignment Day. Measurement of these petroglyphs on the rubbing of the panel and on the photograph reproduced in Figure 6a indicates that the center of the "nothing there" symbol is located .27 $\pm$.01 of the way from the center of the north to the center of the south moon symbol, or $8^{\mathrm{d}}.0 \pm^{\mathrm{d}}.3$ after Alignment Day. Since the region is "empty" on this date, the exodus had to occur at least one day earlier. We shall therefore assume, in the discussion which follows, that "Departure Day" was 7^{d} after Alignment Day. Actually, it is probably more realistic to suppose that there was a "departure period," which began with Alignment Day and lasted for seven days. Departure Day, as just defined, marks the end of that period and represents the last day on which safe exit from the region was still guaranteed.

That this interpretation of the central section of the panel is correct is suggested by the spacing of the two moon symbols. Suppose that the author of the panel wished to confirm to the reader that the two moon symbols do represent the interval of one lunation following alignment. He could do this by locating these symbols so as to match the angular motion of the sunrise point along the skyline during that period.

The angle, s, between the centers of the two moon symbols, as seen from the bear track, was measured on the rubbing of the panel. The locations of the centers of the bear track and the northern moon symbol are slightly uncertain owing to their irregular outlines. In the present measures, the center of the bear track was taken to be the midpoint of the line bisecting the transverse widths of the track excluding the claws; the center of the northern moon symbol in the north–south direction was located by bisecting the curves of the eastern and western ends of the symbol. These measures give $s = 17°50'$. The positions of the centers of both the north moon symbol and the bear track could be in error by as much as 1 mm. Such errors will change s by $6'$ and $3'$, respectively, so that the total error in s could be as much as $\pm 7'$.

The change in azimuth of the sunrise point during the period of one lunation following Alignment Day was calculated as follows: At alignment, the skyline altitude is $h = 10°24'$ (the top of Departure Peak). The apparent altitude of the center of the solar disk was taken to be $h_{\odot} = 10°12'$, so that a width of $4'$ of the solar limb appears above the top of the peak. At the sunrise point $29^{\rm d}.5$ later, the skyline altitude was assumed to be $h = 7°48'$, interpolated from transit observations of nearby points. The apparent altitude of the center of the solar disk was therefore $h_{\odot} = 7°32'$. The true altitudes of the center of the solar disk were then found by applying standard values of the atmospheric refraction taken from the *Refraction Tables* published by the Pulkova Observatory (Fifth Edition, 1985). These calculations give $\Delta A = 11°32'$, significantly less than the angle, s, measured on the panel. However, if our interpretation of the panel is correct, the observer was no longer present one lunation after alignment to make the necessary measurements. Thus, even though he would have almost certainly been aware that the motion of the sunrise point would be different, the best he could do would have been to observe the position of the sunrise point one lunation *before* alignment and to use that measured angle in constructing the panel.

We therefore calculate the azimuth of the sunrise point one lunation before optimum alignment which, as indicated above, we shall define as being the sunrise on October 12, 1998. The altitude of the skyline at this point is $h = 7°20'$, measured on a photograph of the eastern horizon as seen from MFM, so that the apparent altitude of the center of the solar disk was $h_{\odot} = 7°04'$. Correcting for refraction as above, we obtain the values of ΔA given on the top line of Table 2A. As can be seen from the table, the agreement of ΔA with s is now very good, suggesting that the spacing of the two moon symbols was indeed based on the motion of the sunrise point during the lunation preceding alignment.

Table 2. Angular Distance Between Sunrise Point and Departure Peak.

A: Calculated Azimuth Difference (ΔA)

Epoch Year	Number of Days Before Alignment		
	–29.0	–29.5	–30.0
+2000	17°34'	17°49'	18°04'
+1000	17°46'	18°02'	18°17'
+ 01	18°00'	18°15'	18°30'
–1000	18°12'	18°27'	18°43'
–2000	18°22'	18°38'	18°54'

B: Calculated Separation (S)

Epoch Year	Number of Days Before Alignment		
	–29.0	–29.5	–30.0
+2000	17° 37′	17° 52′	18° 07′
+1000	17° 49′	18° 04′	18° 19′
+ 01	18° 03′	18° 17′	18° 32′
–1000	18° 14′	18° 29′	18° 44′
–2000	18° 24′	18° 40′	18° 55′

C: Corrected Separation (S_c)

Epoch Year	Number of Days Before Alignment		
	–29.0	–29.5	–30.0
+2000	17° 24′	17° 40′	17° 54′
+1000	17° 36′	17° 52′	18° 06′
+ 01	17° 50′	18° 04′	18° 20′
–1000	18° 02′	18° 16′	18° 32′
–2000	18° 12′	18° 28′	18° 42′

Note: Angle measured on the panel = 17° 50′.

The observer most probably made his measures of the sunrise positions using a cross-staff, consisting of two pieces of wood fastened together to form a T. The observer looked from the base of the T through a small defining slit or aperture to eliminate errors resulting from changes in the position of his eye. He noted the positions of the sunrise point and the top of Departure Peak with respect to reference marks on the crossbar of the T, then used these measures to lay out the required angle on the panel. Observing in this way, what was being measured was not precisely the azimuth difference, ΔA, but rather the angular distance, S, between the sunrise point and Departure Peak. The values of S calculated from the azimuth differences in Table 2A, for a skyline altitude at sunrise of $h = 7°20'$ one lunation before alignment and $h = 10°24'$ at alignment, are given in Table 2B. Direct measurements of S were made by photographing the actual sunrise one lunation before alignment and measuring from the sunrise point along the sloping line to the top of Departure Peak. The linear measurements on the photographs were then converted to angular measure using the focal-plane scale for the camera lens derived from measurements of photographs of star fields taken with that lens. Sunrise observations were made on September 12 and 13, 1999, when the positions of the sunrise points were $\Delta S = -7'$ north of the locations they would have had in 1998, when the optimum alignment of the rising sun with Departure Peak occurred. Correcting the observations to 1998, we obtain:

$$S = 17°51' \; -30^{\rm d}.0 \text{ before alignment, and}$$
$$S = 17°28' \; -29^{\rm d}.0 \text{ before alignment.}$$

Comparing with Table 2B, we see that these values give:

$$\Delta\, S = S_{\rm obs} - S_{\rm calc} = -0°16' \text{ for } -30^{\rm d}.0 \text{ before alignment, and}$$
$$\Delta\, S = S_{\rm obs} - S_{\rm calc} = -0°09' \text{ for } -29^{\rm d}.0 \text{ before alignment.}$$

The difference between the two values of ΔS results primarily from the errors of measurement of the photographs, mainly the uncertainty in locating the precise sunrise point within the overexposed image of the solar limb. Averaging the two observations, we have $\overline{\Delta S} = -0°12' \pm 4'$.

The source of this discrepancy is evident from an inspection of Figure 10: owing to the geometry of the Alignment Day sunrise, the azimuth of the center of the solar disk at optimum alignment is slightly larger than the azimuth of the top of the peak. The precise value of this offset is uncertain since, owing to clouds, it was not possible to obtain measureable photographs on October 12, 1998. Thus, the exact location of the path of the center of the solar disk on this date is not known. Clearly, the most reliable values of S are those given by the photographic observations, which yield the corrected values, S_c, listed in Table 2C, where $S_c = S + \overline{\Delta S}$. These values will be used in the discussion which follows.

The orbit of the earth varies with time. As a result, the azimuth of the sunrise point one lunation before alignment was smaller, and its angular distance from Departure Peak larger, in the past than at present. Values of ΔA, S, and S_c, calculated using sun positions derived from the JPL Ephemeris Program (Giorgini et al. 1996:1158),[3] are listed in Tables 2A, 2B and 2C, respectively, for different epochs and for different numbers of days before alignment. These tables show that today $S_c \simeq s$ $30^{\rm d}.0$ before alignment. However, in the past best agreement between S_c and s occurs for an interval of $-29^{\rm d}.0$ in about A.D. 0, and for $-29^{\rm d}.5$ in A.D. 1000. The accuracy of these results is rather low owing to the measurement errors of s and S_c, as well as to uncertainty as to precisely what aspect of the sunrise at Departure Peak would have been considered optimum by the observer; e.g. aligning with the north side would decrease S_c by about $9'$. Nevertheless, if the observer used an interval of $-29^{\rm d}.0$ for the length of the synodic period, then the time-period of the construction of the panel inferred from Table 2C is reasonably consistent with the archaeological studies, which indicate that the petroglyphs in this region were made by the Martis Complex Indians, who were active in the area from about 2000 B.C. to A.D. 500, with a peak of activity around 1500 B.C. (Elsasser 1960:74–75, Gortner 1986:25).

Note that also as a result of the changes in the earth's orbit, alignment of the sun with Departure Peak occurred earlier (i.e., closer to the equinox) in the past than at present. The difference is, however, negligible, amounting to only $-.^{\mathrm{d}}58$ in A.D. 0 and $-1.^{\mathrm{d}}03$ in 2000 B.C.

There remains one final question: How was the azimuth of the line through the centers of the two moon symbols and the "nothing there" symbol chosen? We note from Figures 3 and 6a that this line is not perpendicular to the line joining the bear track and sun symbols, nor is it parallel to the "going out" line and the sides of the "nothing there" square. Measuring the rubbing pictured in Figure 3, we find that this line makes an angle of $\Delta A = 42.^{\circ}5 \pm .^{\circ}3$ with the line through the centers of the bear track and sun symbols. It would appear that this angle might have been chosen in order to represent the direction of the ridge line southward from Departure Peak, above which the sun rises in the lunation following its alignment with that peak. We have seen that the MFM observer measured an angle of $s = 17.^{\circ}9$ for the motion of the sunrise point during this lunation. Laying off that angle on the topographic map brings us to a point just south of a peak labeled "8089 ft." While the ridge line is not very straight, if one draws a straight line from just north of "8089 Peak" to along the ridge that descends northwestwards from Departure Peak, one finds that this line makes an angle of $\Delta A = 41°$with the line from MFM to Departure Peak. This is, however, a rather uncertain result, since by choosing a different portion of the ridge line, angle differences as large as about $\Delta A = 50°$could be obtained. On the other hand, an angle of $\Delta A = 30°$, as given by the "going out" line, would not represent the ridge-line direction at all. Thus, the azimuth of the center line of the "nothing there" and moon symbols may have been chosen to further indicate to the reader that these symbols do refer to the motion of the sunrise point along the skyline during the lunation following Alignment Day.

Finally, then, the message of the panel reads:

> "Eight days after the rising sun, moving southward along the skyline, aligns with the peak indicated by this panel, the valley area shown on the panel is "empty" because the people in it have "gone" out in the direction shown, along a trail that becomes difficult just where it leaves the valley."

A crucial test of the above interpretation is: does it work? If one leaves the valley no later than one week after Alignment Day, does one in fact avoid getting caught in the first severe autumn storm? The condition one wants to avoid is that of having snow on the ground, making travel difficult or impossible. This would presumably be assessed in terms of the snow on the ground at MFM since this could be easily and directly observed, whereas monitoring conditions on the higher passes would be more difficult, and would be unnecessary if it were known that the passes could be traversed as long as there was no snow on the ground at MFM. The question is, then, if one leaves the valley before the "empty" date indicated by the panel, will one avoid having snow on the ground at MFM?

No snowfall observations exist for MFM. Thus, to investigate this question, the snowfall records from the five nearest weather stations were examined. These stations are listed in Table 3.Since 1949, the daily snowfall and amount of snow on the ground have been given in the *Climatological Record, California*, published by the Weather Bureau, U.S. Department of Commerce. Before 1949, these measures were not published, and are available only on the weather station observer's original record sheets. Copies of these records were therefore obtained from the NOAA National Data Center, U.S. Department of Commerce. A few of the weather stations in the central region of California began observations in the late 1800s. However, in the early 1900s these records were being archived in the U.S. Weather Bureau office in San Francisco, and were destroyed by the fire that followed the 1906 earthquake. Thus, the earliest surviving snowfall observations at any of these stations date only from 1904, and some of the stations listed in Table 3 began operation even later.

The closest station to MFM is Soda Springs. However, snowfall coverage at this site is not very good, extending only from 1915–1969, and with no observations from 1918–1929. The next closest station is Tahoe City, which has snowfall coverage from 1915 to the present, with no snowfall observations from 1923–1938. Tahoe City is located some 18 km (11 mi) east of MFM and at approximately the same elevation, but on the opposite (eastern) side of the Sierra crest. For this station, the days when snow fell and/or was present on the ground between September 1 and December 31 were plotted for each year from 1939–1997, as shown in Figures 15–17. In these figures, the ordinate is the year, and the abscissa is the day of the month. Days with snowfall are indicated by circles, while days with snow on the ground are indicated by dots. The Alignment and Departure dates (October 12 and 19) are indicated by the two vertical lines.

Inspection of Figures 15–17 shows that the dates given by the panel do, in fact, occur just before the onset of the autumn snows. Between 1939 and 1997, snow lasting more than one day on the ground occurred prior to Alignment Day in only three years, and prior to Departure Day in only six years. We do not know, of course, how much snow would have been considered too much by the Indians. As discussed above, the important point would presumably have been to avoid being trapped by the first really severe snowstorm; one could probably tolerate a moderate snowfall if one could be certain that it would all melt within a few days, permitting exodus from the region over totally or nearly snow-free ground.

Inspection of the data in Figures 15–17 suggests two possible criteria:

(1) The date of the first snowfall lasting four days or longer on the ground.

(2) The date of the first snowfall lasting ten or more days on the ground.

Table 3. Day Number, First Snowfall Lasting $\geqslant 4^{\mathrm{d}}$ and $\geqslant 10^{\mathrm{d}}$ on the Ground.

A: Observed Average Day Number[a]

Station[b]	Elevation m (ft)	Side of Crest	Interval Year 1900+	Observed Average Day Number of First Snowfall Lasting: $\geqslant 4^{\mathrm{d}}$ $\overline{D}$	$\sigma_{\overline{D}}$	N	$\geqslant 10^{\mathrm{d}}$ $\overline{D}$	$\sigma_{\overline{D}}$	N
BC1[c]	1431 (4695)	W	04–27	92.7	3.9	22	97.2	3.3	20
BC2[c]	1448 (4750)	W	28–43	92.2	5.4	15	95.6	6.0	12
BC3	1610 (5283)	W	46–88	75.3	2.6	38	84.5	2.6	34
SS	2058 (6752)	W	15–69	63.2	2.0	40	70.8	2.4	38
MFM	1829 (6000)	W	—	73.9[d]	—	—	80.9[d]	—	—
TC	1899 (6230)	E	15–97	73.2	1.9	64	83.4	2.2	61
T	1829 (6000)	E	07–98	77.8	2.1	65	88.1	2.0	59
B	1687 (5535)	E	12–98	84.3	2.0	59	92.8	1.9	53

[a] Day zero is August 31; N is number of years with observations.
[b] BC = Blue Canyon, SS = Soda Springs, TC = Tahoe City, T = Truckee, B = Boca.
[c] Combining all observations from Blue Canyon Stations No. 1 and No. 2:
for $\geqslant 4^{\mathrm{d}}$ gives $\overline{D} = 92.5$, $\sigma_{\overline{D}} = \pm 2.9$, $N = 37$; for $\geqslant 10^{\mathrm{d}}$ gives $\overline{D} = 96.6$, $\sigma_{\overline{D}} = \pm 2.9$, $N = 32$.
[d] Calculated, using relation shown in Figure 20.

B: Variation of Average Day Number with Time[a]

Station[b]	Least Squares Solution[c] Average Day Number of First Snowfall Lasting: $\geqslant 4^{\mathrm{d}}$ $\overline{D}_{\mathrm{O}}$	$\sigma_{\overline{D}_{\mathrm{O}}}$	$\overline{D}'$	$\sigma_{\overline{D}'}$	t^d	$\geqslant 10^{\mathrm{d}}$ $\overline{D}_{\mathrm{O}}$	$\sigma_{\overline{D}_{\mathrm{O}}}$	$\overline{D}'$	$\sigma_{\overline{D}'}$	t^d
BC3	87.4	15.6	− .177	.22	.79	77.9	15.5	+ .094	.22	.42
SS	64.9	2.3	− .037	.16	.24	68.5	2.4	+ .051	.19	.27
TC	57.9	1.9	+ .246	.02	3.03	69.3	2.0	+ .225	.08	2.70
T	83.9	2.0	− .085	.08	1.15	95.1	1.9	− .108	.08	1.34
B	78.7	1.9	+ .089	.09	1.04	87.5	2.0	+ .082	.10	.83

[a] Day zero is August 31.
[b] See notes to Table 3A, above.
[c] Average Day Number $\overline{D} = \overline{D}_{\mathrm{O}} + \overline{D}'$ (year – 1900).
[d] Student's t test; $t_{.05}$ (95% confidence level) varies from 1.69 for $N = 38$ to 1.68 for $N = 40$–53 and 1.67 for $N = 59$–65.

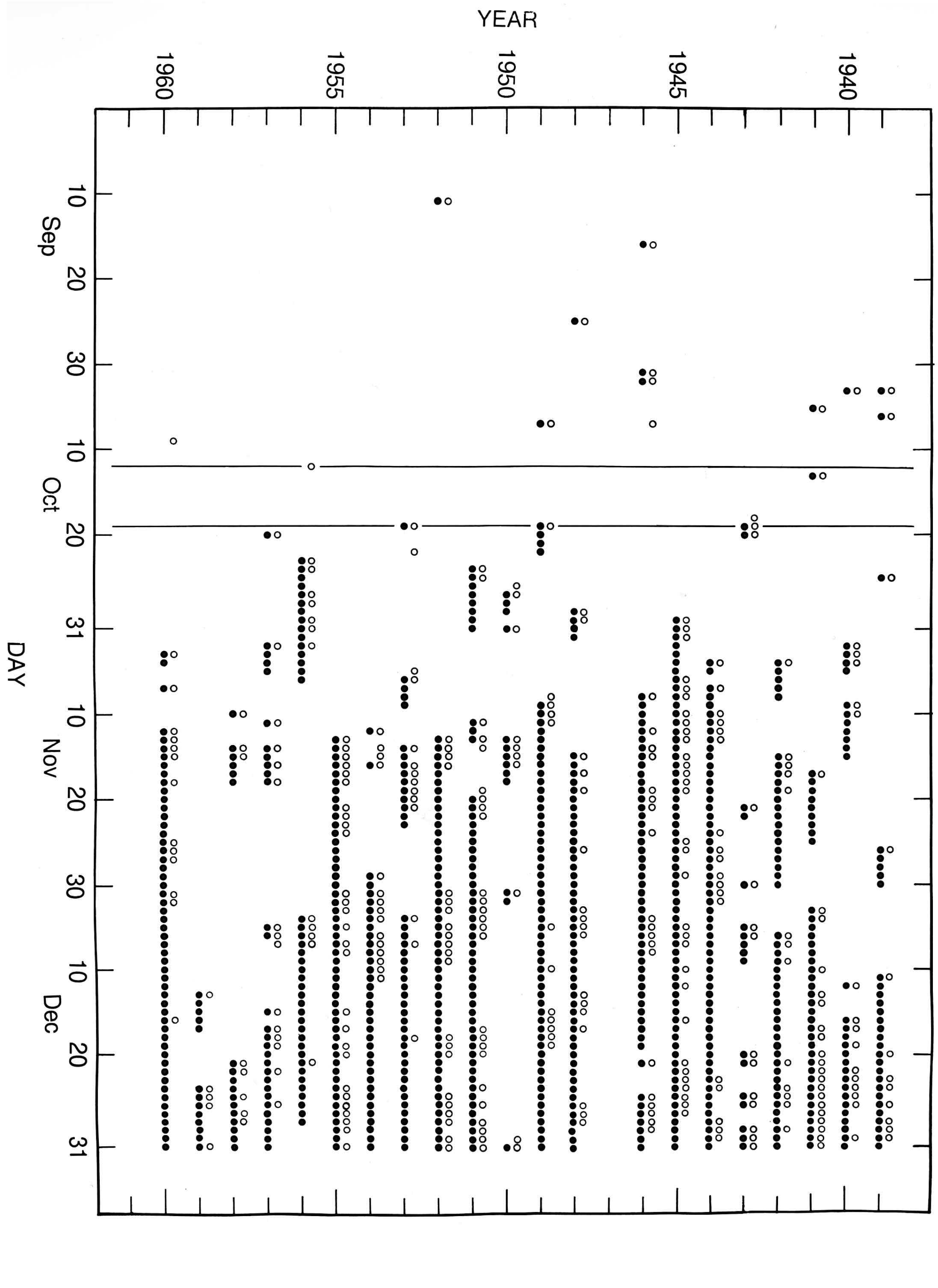

Figure 15. Snowfall at Tahoe City. I. Ordinate, Year; abscissa, Date in given year. Circles, dates with measurable snowfall. Dots, dates with snow on the ground. Vertical lines: Left-hand line, date of alignment of sun with Departure Peak at MFM. Right-hand line, departure date indicated by the petroglyph panel at MFM.

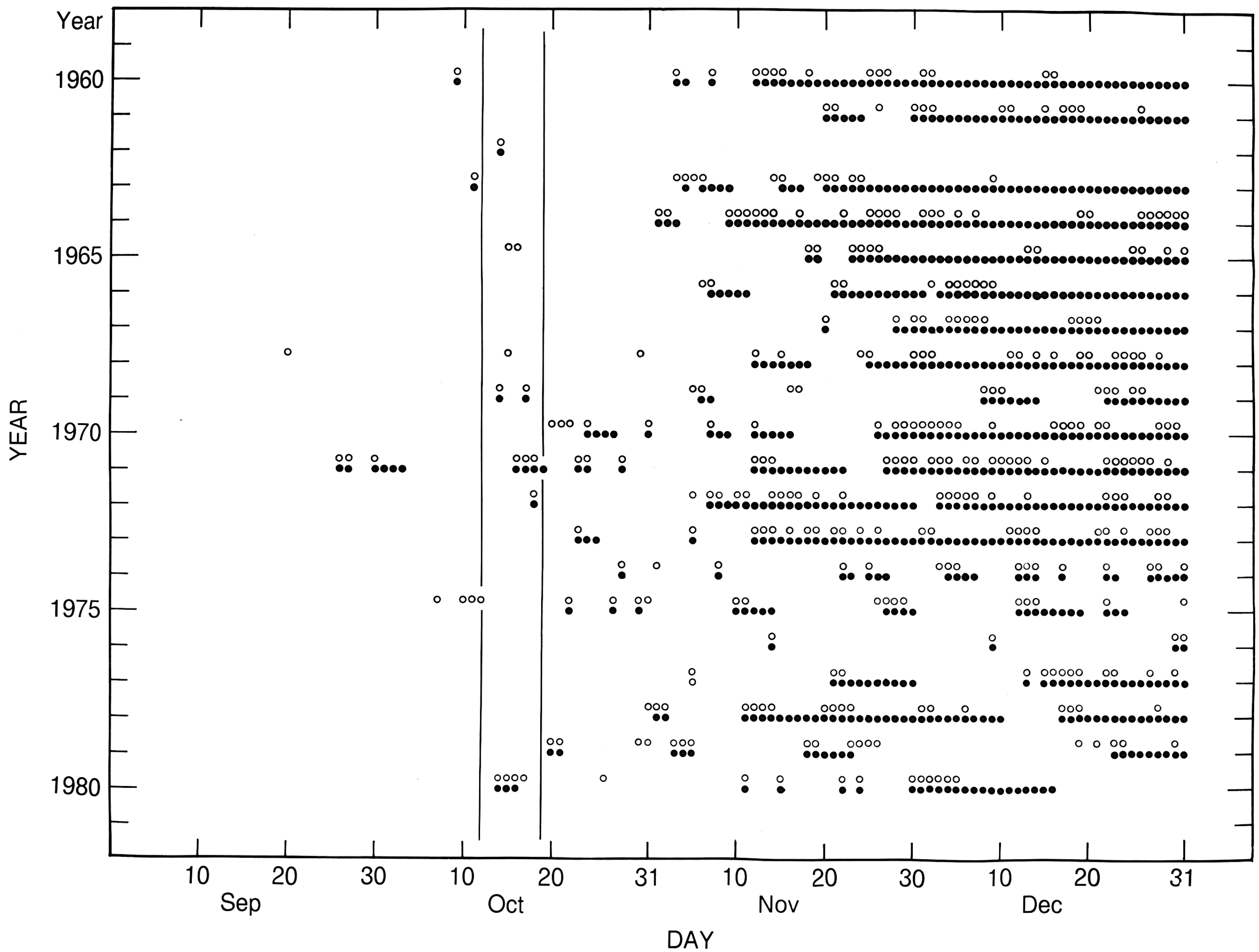

Figure 16. Snowfall at Tahoe City. II. Ordinate, abscissa, and symbols as in Figure 15.

As can be seen from the figures, the latter date corresponds fairly well to the date when the region becomes permanently snowbound for the winter, and is therefore a date by which one would certainly want to be out of the high mountains. The former date corresponds more or less to the first moderate snowfall; one would, for convenience, like to avoid this snowfall, but being caught by it would probably not be too serious as one could just wait a few days for the snow to melt. At such a time, it seems likely that the snow depth even on the passes would not be so great as to prevent foot travel over them.

Adopting these criteria, the dates of the first snowfall lasting four or more and ten or more days on the ground were plotted for all of the years with snowfall observations for each of the weather stations listed in Table 3. These observations are shown in Figures 18 and 19. In these figures, the ordinate is the day number, day one being September 1, and the abscissa is the year of the observation. Means and least squares fits to the observations were then computed, yielding the values given in Table 3. The least squares solutions are shown by the solid lines in Figures 18 and 19. Note that the weather station at Blue Canyon has been relocated twice: first in 1928 and then again in 1945. The change in 1945 resulted in significantly earlier dates of first $\geqslant 4^{\mathrm{d}}$ and $\geqslant 10^{\mathrm{d}}$ snowfall, apparently due not only to the higher elevation, but also to the substantially greater precipitation, and lower maximum and higher minimum diurnal temperatures at this station, as discussed in the Appendix. Consequently, separate least squares solutions were derived for the observations before and after 1945.

Table 3B shows that no statistically significant variation with time in the dates of first snowfall occurred except in the case of Tahoe City. These observations are discussed in more detail in the Appendix.

The dates of first snowfall at the various weather stations will, of course, differ from the date at MFM owing to differences in their elevations and locations in the Sierra range. Thus, to verify that the panel dates at MFM do precede the first significant snowfall at that site, we must first investigate the way in which the first-snowfall date varies with location in the Sierras. Figure 20 shows a plot of the average dates of the first $\geqslant 4^{\mathrm{d}}$ and $\geqslant 10^{\mathrm{d}}$ snowfall for the various weather stations. In this figure, stations west of the Sierra crest are indicated by dots, and stations east of the crest by circles. The ordinate is the elevation of the station in meters, and the abscissa is the average day number, $\overline{D}$, $D = 0$ being August 31. Note that for Tahoe City, $\overline{D}$ was calculated from all of the observations, from 1915–1997. However, for Blue Canyon only the observations from Stations 1 and 2 have been used, for the reasons discussed in the Appendix.

Inspection of Figure 20 shows:

(1) The date of the first $\geqslant 4^{\mathrm{d}}$ and $\geqslant 10^{\mathrm{d}}$ snowfall becomes earlier with increasing elevation.

(2) For a given elevation, the first $\geqslant 4^{\mathrm{d}}$ and $\geqslant 10^{\mathrm{d}}$ snowfalls occur earlier at stations west of the Sierra crest than at those east of the crest.

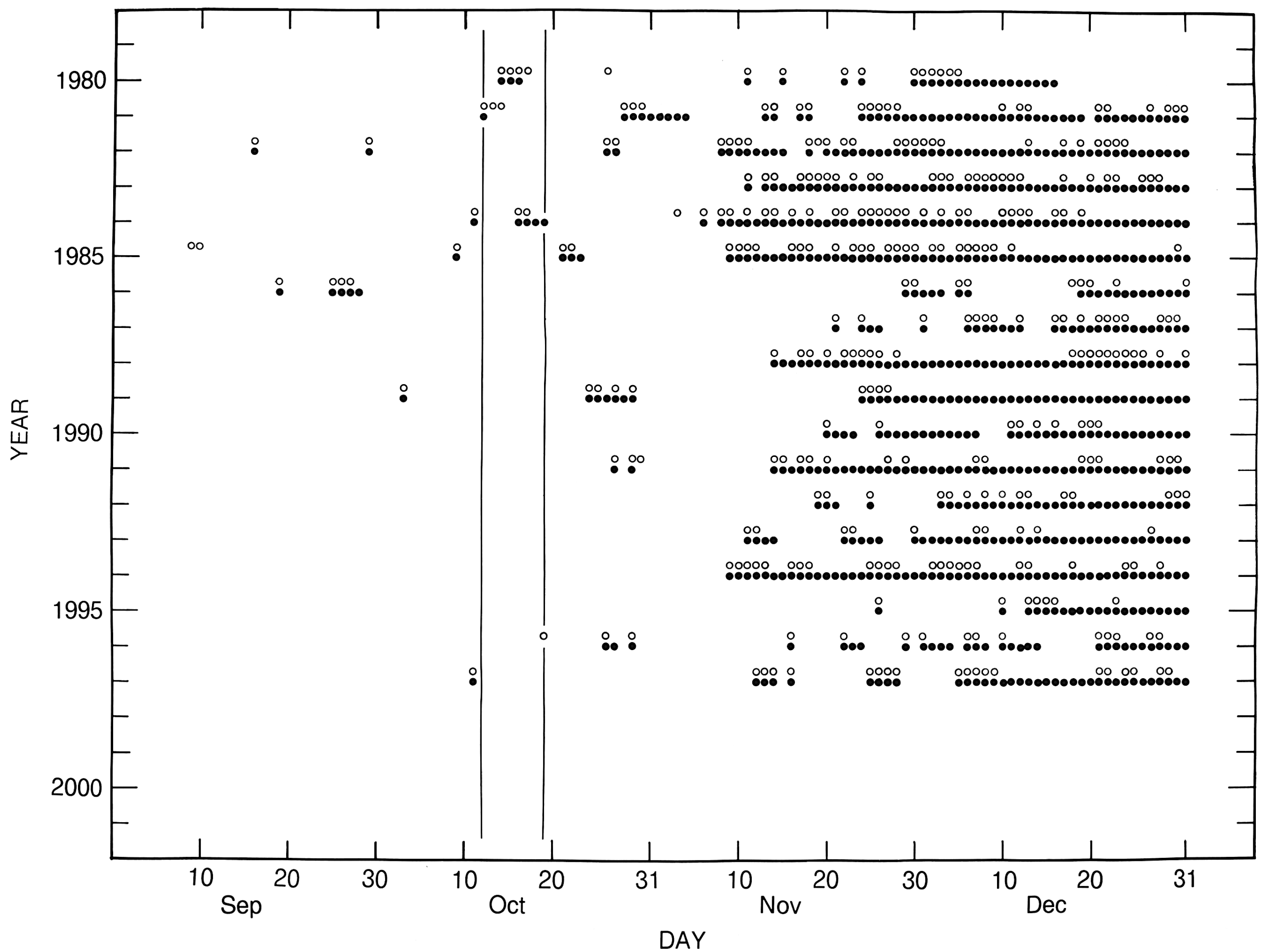

Figure 17. Snowfall at Tahoe City. III. Ordinate, abscissa, and symbols as in Figure 15.

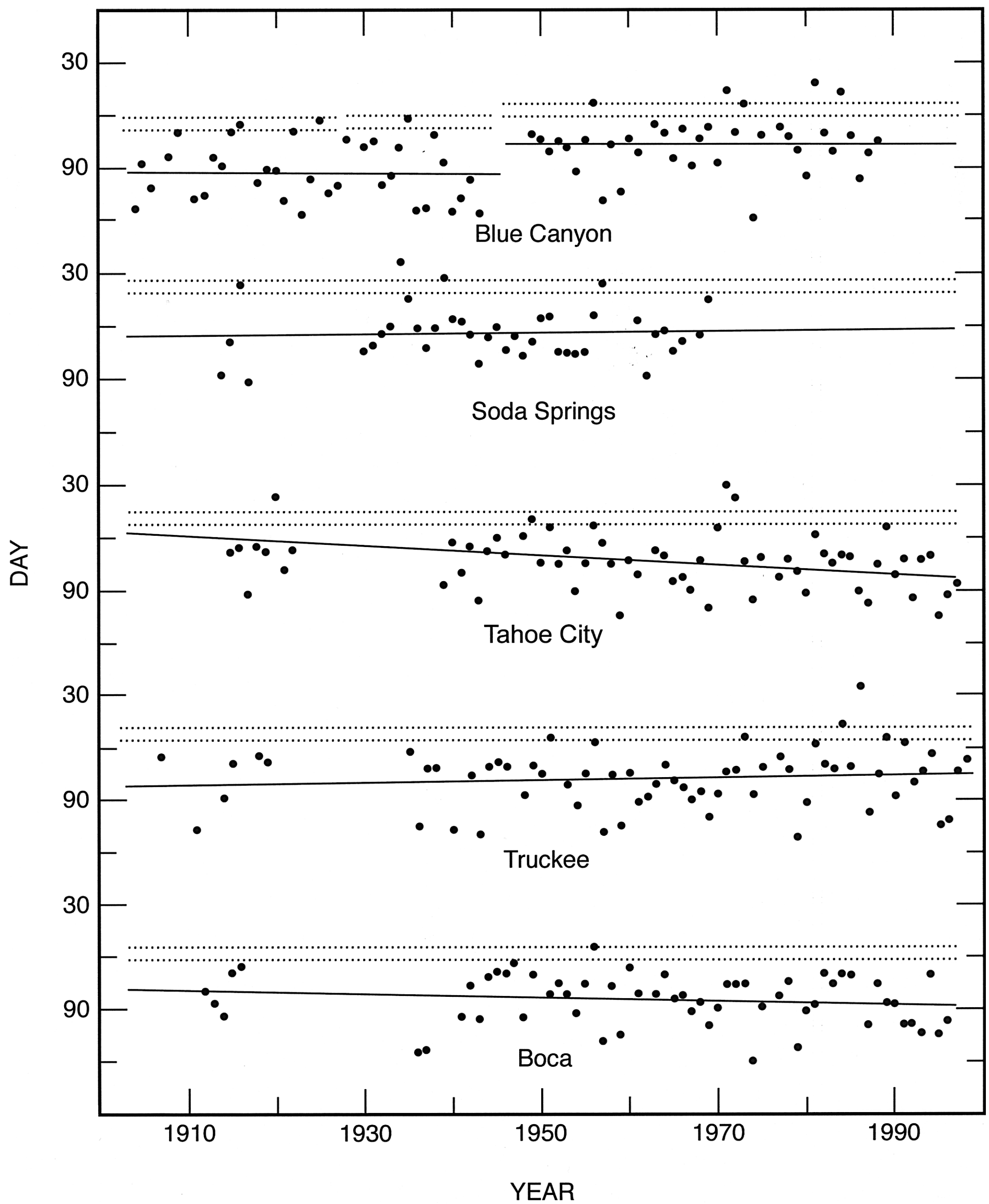

Figure 18. Dates of first snowfall lasting $\geqslant 4^{d}$ on the ground at the various Sierra weather stations. Ordinate, Day number (Day 1 = Sept. 1). Abscissa, Year. Solid lines: least squares fit to the observations. Dotted lines, Alignment and Departure dates given by the petroglyph panel at MFM, adjusted to the location of the particular weather station. The discontinuous lines for Blue Canyon result from changes in the location of the weather station. See text.

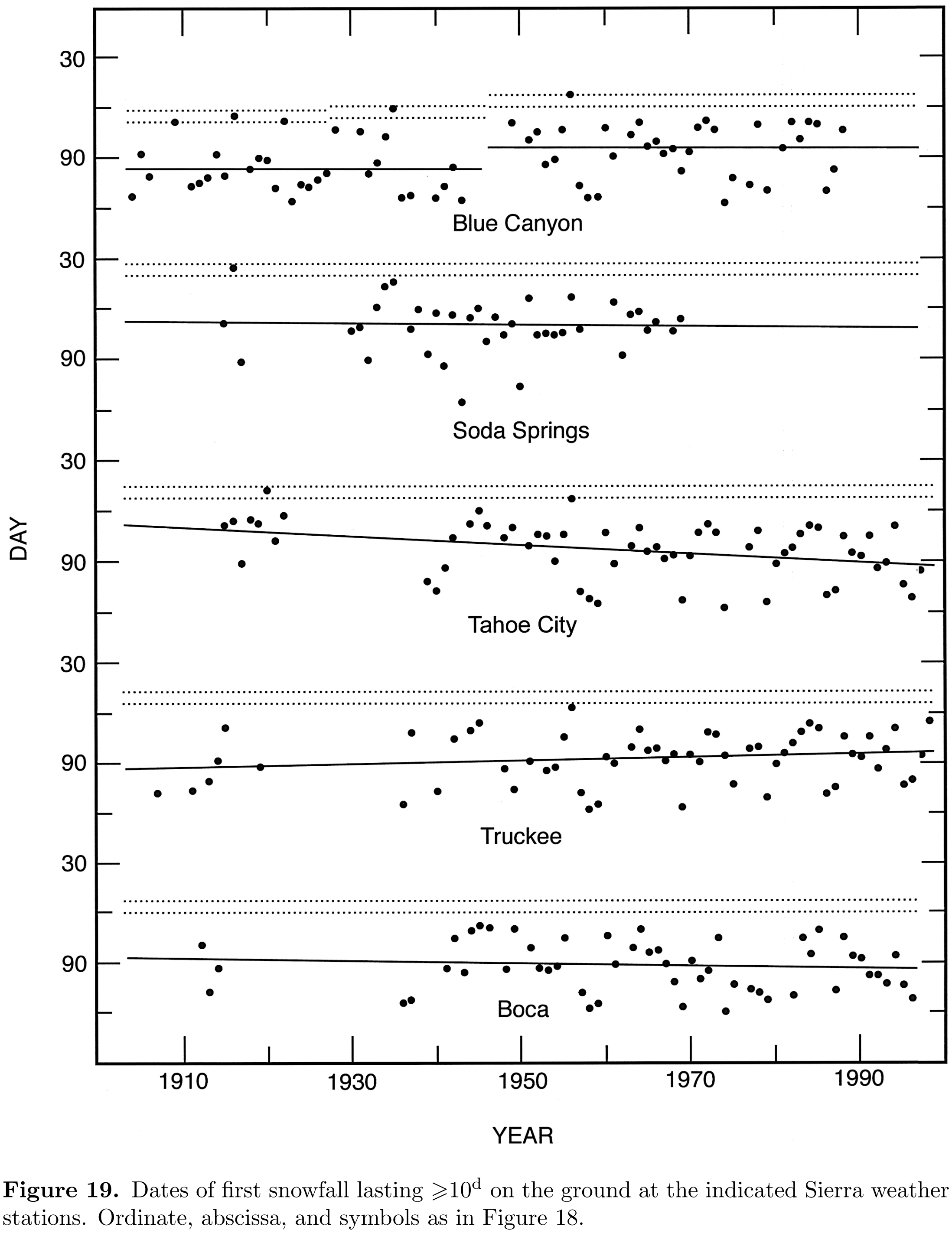

Figure 19. Dates of first snowfall lasting $\geqslant 10^{d}$ on the ground at the indicated Sierra weather stations. Ordinate, abscissa, and symbols as in Figure 18.

Table 4. Correction of MFM Alignment and Departure Dates to Weather Stations.

Station	Elevation Station − MFM m	Elevation Correction[a] days	East–West Correction[b] days	Total Correction days
Blue Canyon No. 1	−398	+17.6	0	+17.6
Blue Canyon No. 2	−381	+16.8	0	+16.8
Blue Canyon No. 3	−219	+ 9.6	0	+ 9.6
Soda Springs	+229	−10.1	0	−10.1
Tahoe City	+ 70	− 3.1	+5.0	+ 1.9
Truckee	0	0	+5.0	+ 5.0
Boca	−142	+ 6.3	+5.0	+11.3

*N*ote: At MFM, Alignment and Departure Days are $D = 42$–43 and $D = 49$–50, respectively.
[a] The change with elevation (assumed the same for east and west sides of the Sierra crest) is −.0441 day/m.
[b] West- to East-slope correction is $+5^{\mathrm{d}}.0$ based on Figure 20. (Snowfall dates are later east of the Sierra crest.)

With so few stations, the precise forms of these two relations are not well defined. Tentatively, parallel best-fit lines have been drawn through the observations as shown in the figure, the relationship for the first $\geqslant 4^{\mathrm{d}}$ snowfall being indicated by dotted lines and for the first $\geqslant 10^{\mathrm{d}}$ snowfall by solid lines. These lines correspond to a change in first snowfall date with elevation of $-^{\mathrm{d}}.0441$/m ($-^{\mathrm{d}}.1447$/ft), and to delays of $3^{\mathrm{d}}.4 \pm 1^{\mathrm{d}}.7$ and $6^{\mathrm{d}}.8 \pm 1^{\mathrm{d}}.7$, respectively, in the dates of the first $\geqslant 4^{\mathrm{d}}$ and $\geqslant 10^{\mathrm{d}}$ snowfalls on the east, compared to the west slope of the Sierras; in view of the uncertainties, we shall adopt a difference of $5^{\mathrm{d}}.0$ between the west and east slopes in the discussion which follows.

Using the relationship shown in Figure 20, we may now correct the "Alignment" and "Departure" dates given by the MFM panel to the locations of the various weather stations. These dates are listed in Table 4, and are indicated by the dotted lines in Figures 18 and 19. From these figures, we see that snowfalls lasting $\geqslant 4^{\mathrm{d}}$ on the ground occurred prior to the adjusted Alignment Day in only three years at Blue Canyon, one year at Soda Springs, three years at Tahoe City and none at Boca. By the adjusted "Departure Day," $\geqslant 4^{\mathrm{d}}$ snows had occurred at these stations in eight, four, four, five and one year, respectively. Snowfalls lasting $\geqslant 10^{\mathrm{d}}$ on the ground did not occur prior to the adjusted Alignment Day at any of the stations, and occurred prior to the adjusted Departure Day in two, one, one, zero and zero years, respectively.

These results demonstrate that, at least at present, the departure date given by the panel does occur just before the onset of the first significant snowfall at MFM. Probably this was also true when the panel was created. As discussed above, the panel probably dates from the period between about 2000 B.C. and A.D. 01, and it is thought that during that time, the climate was much the same as at present (LaMarche 1976:1043, Gortner 1986:48).

It is possible that the number of days from Alignment Day to Departure Day is also given by the number of rays in the sun symbol. As discussed in Part One, the simplest and easiest way of generating a uniformly spaced ray pattern was to repeatedly bisect the arcs of the circle, giving sets of either 2, 4, 6, 8, 16, ... rays. Other numbers of rays were more difficult to space evenly, and there is an indication that these numbers were employed in response to some specific need, in particular as day counts for timing sun-related events. Here, the sun symbol has eleven rays. Inspection of the ray spacing suggests that the pattern can be interpreted as consisting of seven fairly uniformly spaced rays, with four additional rays interpolated between them along the northern and eastern sides of the pattern. Thus, the number of rays may have been intended to provide a more precise day count than that given by the two moon symbols, and the number of rays increased at a later date or dates in order to "fine tune" the day count, after years of observation indicated that the original interval specified by the moon symbols could, in fact, be slightly lengthened. Examination of the snowfall records in Figures 15–19 indicates that lengthening the Alignment—Departure interval from 7^{d} to 11^{d} might well have been possible.

It is interesting to compare the date given by the panel for leaving the Sierra high country with the experiences of the westward-bound emigrants in the 1840s. If the emigrants had known about and had followed the advice of the panel, would they have avoided being caught by the first severe autumn snowstorm?

The first group to cross the Sierras with wagons was the Stephens Party, which traveled over Donner Pass, some 15 km (9 mi) northeast of MFM, in 1844 (Angel 1882:64, Stewart 1953:1). This group left the vicinity of Wadsworth, some 117 km (70 mi) east of Truckee, on October 12 and arrived at the junction of the Truckee River and Donner Creek (near Truckee) on November 14 (Stewart 1953:30). Good weather appears to have lasted until the Party reached the Truckee Meadows, where Reno is now located (Stewart 1962:69). This site is some 50 km (30 mi) from Wadsworth and took "some days" to reach (Stewart 1962:69). Under good conditions, a journey of this length would have taken at least three days (Stewart 1953:100). However, the terrain was difficult, so that a somewhat longer time was undoubtedly needed. Thus, the Party must have arrived several days after October 15. After leaving the Meadows, progress became very slow, and the weather began to deteriorate. A few light snows fell on the surrounding mountain peaks and, later, a heavier storm deposited a foot (30 cm) of snow on the trail itself (Stewart 1962:70). Arriving at the river junction on the evening of November 14, the Party divided, some going on horseback southward to Lake Tahoe, while the wagons continued, the next day, two miles further west to Donner Lake. There, some days were spent in finding a route across the Sierra crest, where the snow was now about 60 cm (2 ft) deep (Stewart 1953:69). Six wagons were left at Donner Lake, while five were taken over Donner Pass, making the crossing on November 25 (Stewart 1953:31, 1962:175). Three men were left to guard the abandoned wagons, and were trapped by the first major snowstorm, which began on November 28 (Stewart 1953:28). Recalling that Alignment Day is October 12 and Departure Day is October 19, we see that had the admonitions

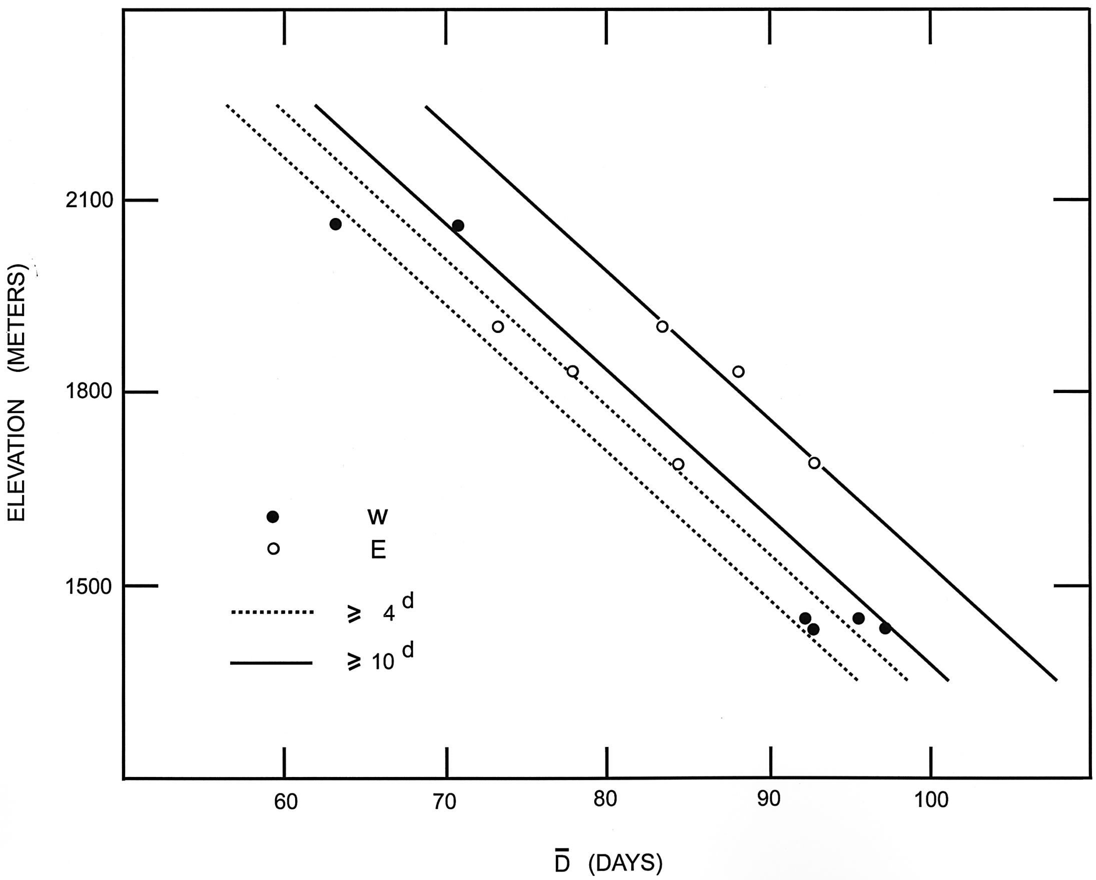

Figure 20. Variation of the average date of first snowfall lasting $\geqslant 4^d$ and $\geqslant 10^d$ on the ground as a function of elevation and side of the Sierra crest. Ordinate, elevation in meters; abscissa, average date of first $\geqslant 4^d$ and $\geqslant 10^d$ snowfall; Day 1 = Sept. 1. Dots indicate stations west of the Sierra crest; circles, stations east of the crest. Dotted lines indicate date of first $\geqslant 4^d$ snowfall; solid lines, date of first $\geqslant 10^d$ snowfall. These lines correspond to a change in first snowfall date with elevation of $-\overset{d}{.}0441$/m.

of the MFM panel been followed, the Stephens Party would have crossed the Sierra crest with (relative) ease, encountering only light snow or none at all, and running no risk of being trapped by the first severe storm of the season.

In fact, 1844 was an average year insofar as the date of the first severe snowstorm is concerned. The storm which began on the evening of November 28 had deposited 91 cm (3 ft) of snow on the ground by the next morning, and snowfall then continued almost without interruption until about the first of December, eventually reaching a depth of some 3 m (10 ft) (Stewart 1953:71–72). This storm thus qualifies as the first $\geqslant 10^{\mathrm{d}}$ snowfall for 1844 at Donner Lake. Now, Donner Lake has an elevation of 1809 m (5935 ft), essentially the same as that of the weather station at Truckee, about 3 km (2 mi) to the east. From Table 3A, we see that the average date of the first $\geqslant 10^{\mathrm{d}}$ snowfall at Truckee between 1907 and 1998 was $\overline{D} = 88^{\mathrm{d}}$ (November 27) $\pm 2^{\mathrm{d}}$, only one day different from its actual occurrence in 1844.

In 1845, the arrival of the first heavy snow was clearly much later. Captain John C. Frémont crossed Donner Pass on December 5 and reported no snow on the ground (Jackson and Spence 1970:28). The Hastings Party also crossed successfully over Donner Pass a few days before Christmas, encountering only a small amount of snow, "not deep enough to be much hindrance" (Stewart 1962:105).

In 1846, the Aram Party crossed the pass at the head of Coldstream Canyon, south of Donner Pass, on September 16; all of the later parties in 1846 also used this route rather than going over Donner Pass (Stewart 1962:175). Other groups crossed around September 26 and October 1 (Stewart 1962:176). On October 6–7, the Mather Party crossed the pass, encountering snow squalls on October 7 (Donald Wiggans, personal communication 2012; based on unpublished accounts by 1840s emigrants). The Chana—Covillaud Party crossed the pass "in safety" "about two weeks before the Donner Party found the way barred by snow" (Angel 1882:65), i.e., about October 15. On October 16, the Young Party succeeded in crossing the pass, but encountered a severe snowstorm at the summit (Stewart 1962:176).

So far, so good. Alignment Day was October 12, so the MFM panel would have predicted that the Aram and Mather Parties would be able to cross over the pass without difficulty. Departure Day was October 19, predicting that the Chana—Covillaud and Young Parties could still get over the pass, though perhaps with some difficulty, as proved to be the case. But now, according to the panel, later parties ran a substantial risk of failure.

The next party to attempt the crossing was the Brown Company. This group crossed the pass on October 27–28 in intermittent snowstorms (Donald Wiggans, personal communication 2012; quoting *The Reminiscences of Mary Jones with the Brown Company in 1846, Elam Brown, Captain*, ms. in the Bancroft Library, University of California, Berkeley, CA 94720). Then, on October 29, the first members of the Donner Party attempted the crossing, and failed (Birney

1934:103). As recorded by Patrick Breen (Teggert 1910), another attempt was made on October 31, which likewise failed. And on this date the first severe storm began, trapping the Party at and near Donner Lake. Snow fell each day thereafter through November 8, and there was snow on the ground at Donner Lake nearly continuously from October 31 through the end of the year.

If we take October 31 ($D = 61^{\mathrm{d}}$) to be the date of the beginning of the first $\geqslant 10^{\mathrm{d}}$ snowfall at Donner Lake in 1846, then comparing with the snowfall observations at Truckee shown in Figure 19, we see that this date is only six days earlier than the upper envelope of the dates of the first $\geqslant 10^{\mathrm{d}}$ snowfalls between 1907 and 1998. During this period, $D \leqslant 70^{\mathrm{d}}$ in eight years, the average for this group being $\overline{D} = 67\overset{\mathrm{d}}{.}1 \pm 1\overset{\mathrm{d}}{.}4$, and in one year, 1956, $D = 57^{\mathrm{d}}$, four days earlier than in 1846. Thus, as regards the date of the first $\geqslant 10^{\mathrm{d}}$ snowfall, 1846 was not much different from the early-snow years of the twentieth century.

In conclusion, then, it appears that had the emigrants of 1844–1846 followed the advice of the panel, they *would* have avoided becoming snowbound.

3

Other Uses of MFM

Was MFM used for any other purpose besides determining the date of departure from the valley? Other astronomical events that could, in principle, have been observed from this location include the solstices and the equinoxes. However, there is no real evidence that this was done. Neither the solstice points nor the point of the equinox align with any outstanding feature along the skyline as seen from MFM. It is interesting to note that, as seen from the bear track, the line of rocks along the south side of the observing platform has its eastern end at about the direction of the winter solstice sunrise. It seems unlikely, however, that the winter solstice was observed at MFM, or at least not very often, since the site is usually buried in snow at that time.

Along the north side of the platform, the line of rocks extends eastward past the line of sight from the bear track to the summer solstice sunrise point, ending at approximately the line of sight to Needle Peak. Again, it seems unlikely that regular observations of the summer solstice were made at MFM, since snow—particularly on the passes over the Sierra crest—is very often still present at this time. However, the sun, at present, aligns with Needle Peak on July 29 or 30, depending on the four-year cycle. This date is late enough that, unlike the solstice, the event would not often have been missed due to delayed arrival at MFM owing to late melting of the winter snows. As seen from MFM, the altitude of Needle Peak is $h = 12°05'$ at its top and $h = 11°55'$ and $11°48'$ at its base on the north and south sides of the peak, respectively. The width of the peak at its base is $S = 0°28'$. It thus has nearly the same angular dimensions as the upper half of the solar disk. The daily motion of the sun on July 29 is (at present) about $\Delta A = +18'$ ($\Delta S = 17'\!.6$), or just over half of both the diameter of the solar disk and the width of the base of Needle Peak. The close match in angular size between Needle Peak and the solar disk can introduce some ambiguity as to which day should be considered the true Alignment Day.

Based on the presently available observations, it appears that the Needle Peak Alignment Day can be identified by using the following rules:

(1) It is Alignment Day if the sun rises less than half the width of

the base of Needle Peak north of its northern base. This was the case on July 29, 2004, when the sun rose about $\Delta S = -6.'9$ north of the north base of the peak.

(2) It is Alignment Day if the sun rises behind the peak and emerges along its south face.

(3) If the sun rises behind the peak and emerges at its southern base, it may either be Alignment Day or, as on July 30, 2004, the day following alignment. In this case, observations on the preceding or following day are needed to determine which is the true Alignment Day.

On July 30, 2004, one day after alignment, the sunrise was very similar in appearance to the sunrise at Departure Peak illustrated in Figure 9: The skyline north of the peak first became illuminated by sunlight scattered from the vegetation at $06^{\rm h}\ 06^{\rm m}\ 27^{\rm s}$ PST. This illumination extended from the base of the peak northward for a distance equal to the width of the base of the peak, or about $32'$. At $06^{\rm h}\ 07^{\rm m}\ 24^{\rm s}$, the illumination had grown stronger but did not yet involve the peak itself. At $06^{\rm h}\ 07^{\rm m}\ 46^{\rm s}$, points of light began to appear half way up the north face of the peak, and at $06^{\rm h}\ 08^{\rm m}\ 01^{\rm s}$, points of light began to appear along the south face as well. At $06^{\rm h}\ 08^{\rm m}\ 12^{\rm s}$, scattered light appeared all around the peak, outlining it with a rim of light. At $06^{\rm h}\ 08^{\rm m}\ 22^{\rm s}$, the scattered light was becoming much stronger along the south side of the peak, and at $06^{\rm h}\ 08^{\rm m}\ 30^{\rm s}$, the solar limb emerged at the southern base of the peak and immediately all detail was lost in the intense glare of the disk.

The July 30 sunrise was quite impressive. However, the geometry of the alignment predicts that on rare occasions an even more spectacular sunrise will occur: When the sun has precisely the right declination at sunrise, the limb of the sun will initially appear just at the northern base of the peak. The intensity of the sunlight will first grow briefly, but will then decrease again until, for just an instant, the solar disk is almost totally eclipsed by the peak, with only bits of the limb appearing all around its profile. Immediately thereafter, the limb will burst forth again along the south face of the peak. This very special appearance will occur very infrequently. At most, it could occur only every four years, and in fact it will occur much less often, since the solar declination must have almost exactly its critical value, $\delta_{\odot^c}$ for the "annular eclipse" to take place. The precise value of $\delta_{\odot^c}$ is not yet known. In 2004, the declination at sunrise on July 29 was $\delta_\odot = +18°34.'7$, and on July 30 was $\delta_\odot = +18°20.'2$, so that $\delta_{\odot^c}$ lies somewhere between these limits. Since the sunrise point on July 29 was only $\Delta S \simeq -6.'9$ north of the northern base of Needle Peak, $\delta_{\odot^c}$ is probably close to $\delta_\odot = +18°31.'3$. However, observations in several different years will be needed to determine its exact value. The visibility of this special phenomenon will doubtless be further compromised by the increasing atmospheric pollution, which now causes the sky near the sun to be very much brighter than in earlier times.

On average, optimum alignment occurs (at present) $39^{\mathrm{d}}.0$ after the summer solstice, and would have provided the observer with the means of making an accurate check of his calendar, i.e., his day count from the solstice. The ability to make such a check might have been very useful to a group that probably, in most years, made their solstice observations at their winter headquarters before coming to their summer encampments near MFM.

One other event which this site could have been used to observe is the date when the sun has a declination half way between the celestial equator ($\delta_\odot = 0^\circ\,00'$) and its value at the summer solstice ($\delta_\odot = +\epsilon$, where ϵ is the obliquity of the ecliptic). This mid-season event was observed by at least one, and possibly two, Indian tribes in southern California, as discussed in the next section. Most probably, this date served a purpose similar to the "mid-quarter" days which were celebrated in prehistoric and medieval times in the British Isles (McCluskey 1989:1). The "mid-quarter" days occurred halfway between the solstices and equinoxes. Apparently, their dates were determined from day counts, by dividing in half the number of days between the equinox and following solstice, or the solstice and following equinox. These days were ceremonial occasions to mark the true beginnings of the seasons, since the seasons lag behind their respective solstices or equinoxes.

The date when $\delta_\odot = +\epsilon/2$ (presently $+11^\circ 43'.17$) is August 22 or 23, depending on the four-year leap-year cycle. The appearance of the sunrise at MFM on this date is shown in Figures 21 and 22. As these figures show, the sun at this time rises behind a rocky promontory on the eastern skyline known locally as Cathedral Rock. Figure 21 reproduces a photograph of the sunrise on August 22, 1998. This sunrise occurred at $06^{\mathrm{h}}\ 19^{\mathrm{m}}\ 48^{\mathrm{s}}$ PST, when $\delta_\odot = +11^\circ 43'.23$, $'.06$ north of its value when $\delta_\odot = +\epsilon/2$. Even though it is slightly off-center, this mid-season sunrise is an impressive event.

Figure 22 shows a tracing from a photograph of the eastern skyline as seen from MFM and illustrates the geometry of the $\delta_\odot = +\epsilon/2$ sunrise. In this figure, the horizontal line is a level line, while the solid inclined lines represent the diurnal path of the center of the solar disk when $\delta_\odot = +\epsilon/2$ (numbered zero) and on the two preceding and following days. The dotted inclined lines indicate the range in the position of the diurnal path on day zero resulting from the four-year leap-year cycle. The disk of the sun ($32'$ in diameter) is shown by the circle. Dots at the ends of the inclined lines show the position of the center of the solar disk when the upper limb first appears above the skyline. Since, as discussed in Part One (Appendix 2), the obliquity of the ecliptic changes with time, the position of the $\epsilon/2$ sunrise point also varies with time, as shown in Table 5. The four dots above the level line indicate, from right to left, the location of the path of the center of the solar disk when $\delta_\odot = +\epsilon/2$ in A.D. 2000, A.D. 01, 2000 B.C. and 4000 B.C. Defining the edges of the top of Cathedral Rock to be the top of the north slope and the north edge of the cleft on the south side of the Rock, Figure 22 shows that owing to the topography of the top, the sun rose above the midpoint of the top

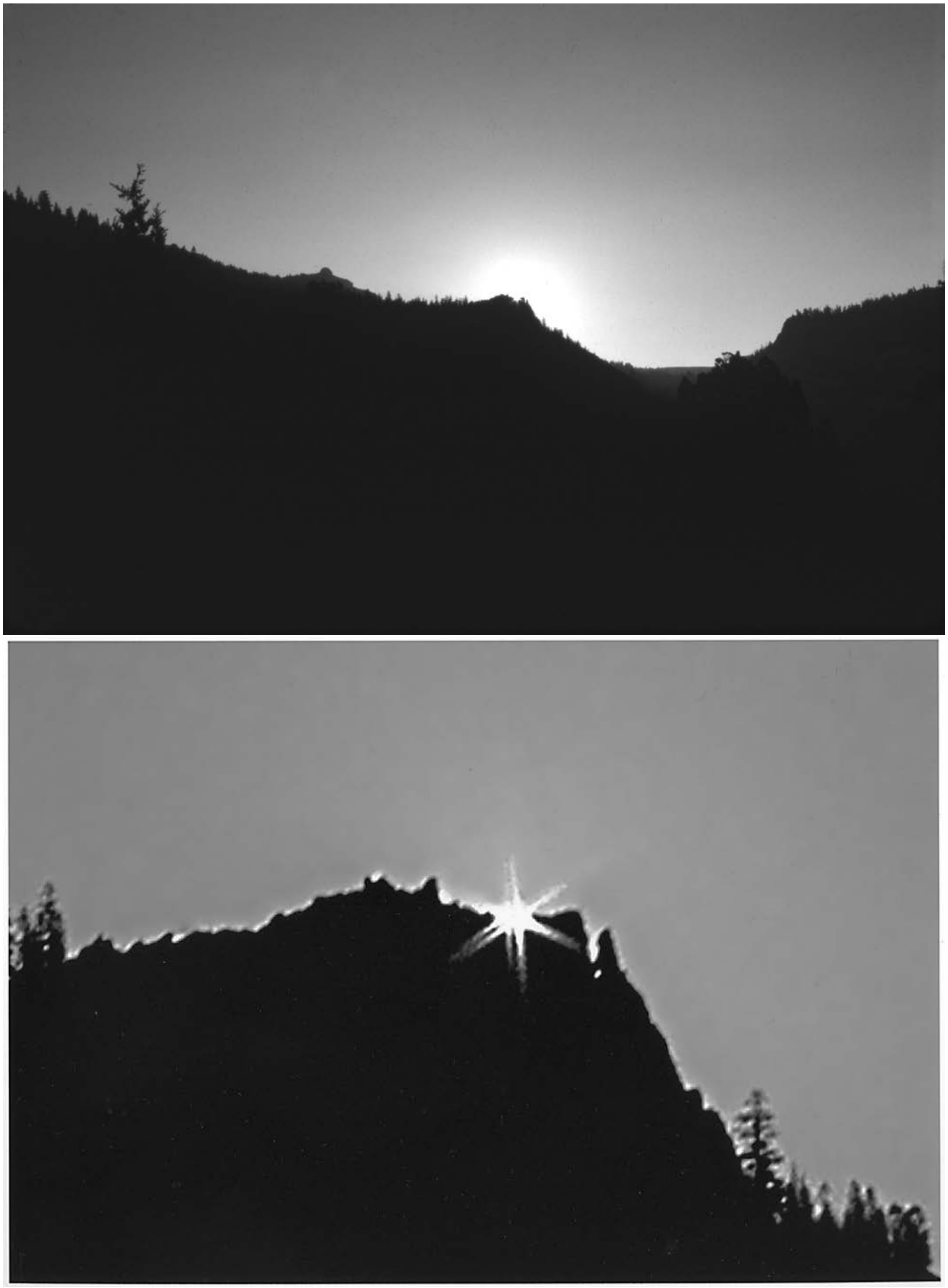

Figure 21. Sunrise at MFM when $\delta_\odot = +\epsilon/2$. Photograph taken 1998 August 22 at 06:19:48 PST, when $\delta_\odot$ was $'.06$ north of its value when the solar declination is exactly $\delta_\odot = +\epsilon/2$ at sunrise. Photograph on Kodachrome 64, 50 mm focal-length lens, exposure 1/250 sec at f/11. In the top view, Cathedral Rock is in the center, and Needle Peak is about half way between the center and left-hand edge of the photograph. The lower picture is an enlargement of the central section of the photograph, showing Cathedral Rock.

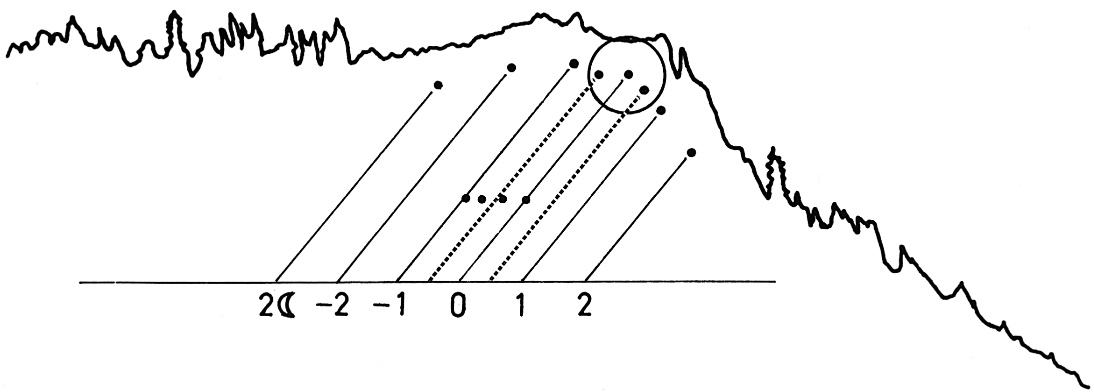

Figure 22. Geometry of sunrise at MFM when $\delta_\odot = +\epsilon/2$. The figure shows Cathedral Rock and adjacent skyline traced from a photograph taken at MFM. The horizontal line is an arbitrary level line. The inclined solid lines indicate the path of the center of the solar disk on successive days. Day zero corresponds to $\delta_\odot = +\epsilon/2$ at sunrise. "2☾ " indicates the path of the center of the solar disk when sunrise occurs exactly two lunations after the summer solstice. The dotted lines indicate the range of the variation in the $\delta_\odot = +\epsilon/2$ sunrise path due to leap year. Dots at the ends of the inclined lines indicate the position of the center of the solar disk when the upper limb first appears above the skyline. The circle indicates the solar disk ($32'$ in diameter) at the $\delta_\odot = +\epsilon/2$ sunrise. Dots above the level line show the position of the path of the center of the solar disk in (right to left): A.D. 2000, A.D. 01, 2000 B.C. and 4000 B.C.

in about 2000 B.C. There is, however, no evidence that such observations were made at MFM at this or any other epoch and, as discussed below, the evidence from site MFN suggests that they were not.

4

MFN

Site MFN is located about 122 m (400 ft) southwest of MFM and, as discussed in the first section, consists of a rounded bedrock outcrop rising some 36 m (120 ft) above the valley floor. A single petroglyph panel is located near the top of the outcrop on its eastern side. This panel is shown in Figures 23, 24 and 25. Figure 23 shows a rubbing of the area surrounding the two symbols that comprise the panel. This rubbing was produced in the same manner as the rubbing of the panel at MFM, described above and shown in Figure 3. Figure 24 reproduces photographs of the two symbols. A photograph of a possible third petroglyph, listed as part of this panel by Gortner (1988), is shown in Figure 25. This petroglyph, located near the center of the figure, appears not to be real but, if real, consists only of random peck marks.

The petroglyphs at MFN are similar in appearance and method of construction to those at MFM. As at MFM, they were pecked into the surface of the glacially polished quartzite bedrock. The widths of the lines in these symbols are similar to those at MFM. Also like those at MFM, these petroglyphs are heavily patinated, indicating that they are very old. This patination makes them difficult to see except when the angle of the sun above the plane of the rock surface is fairly small.

In Figure 23, the up-slope direction is from the bottom to the top of the figure. The figure thus shows the orientation of the panel as viewed by the reader standing on the slope below it. The upper left petroglyph consists of a line, slightly bent in opposite directions at each end, and crossed at right angles by two additional straight lines. Note in Figure 24a that the right-hand end of this line, to the right of the right-hand cross-line, appears to have been made by scraping rather than pecking. The scraped portion is also less deeply incised into the rock surface than are the pecked sections. This suggests either that the entire symbol was originally produced by scraping and that parts were later pecked to enhance their visibility, or that the scraped portion represents a more recent modification of the original pecked symbol. Of these, the former appears to be the more likely since, as can be seen in Figure 24a, the patination of the scraped portion appears to be somewhat greater than that of the pecked areas. The lower right

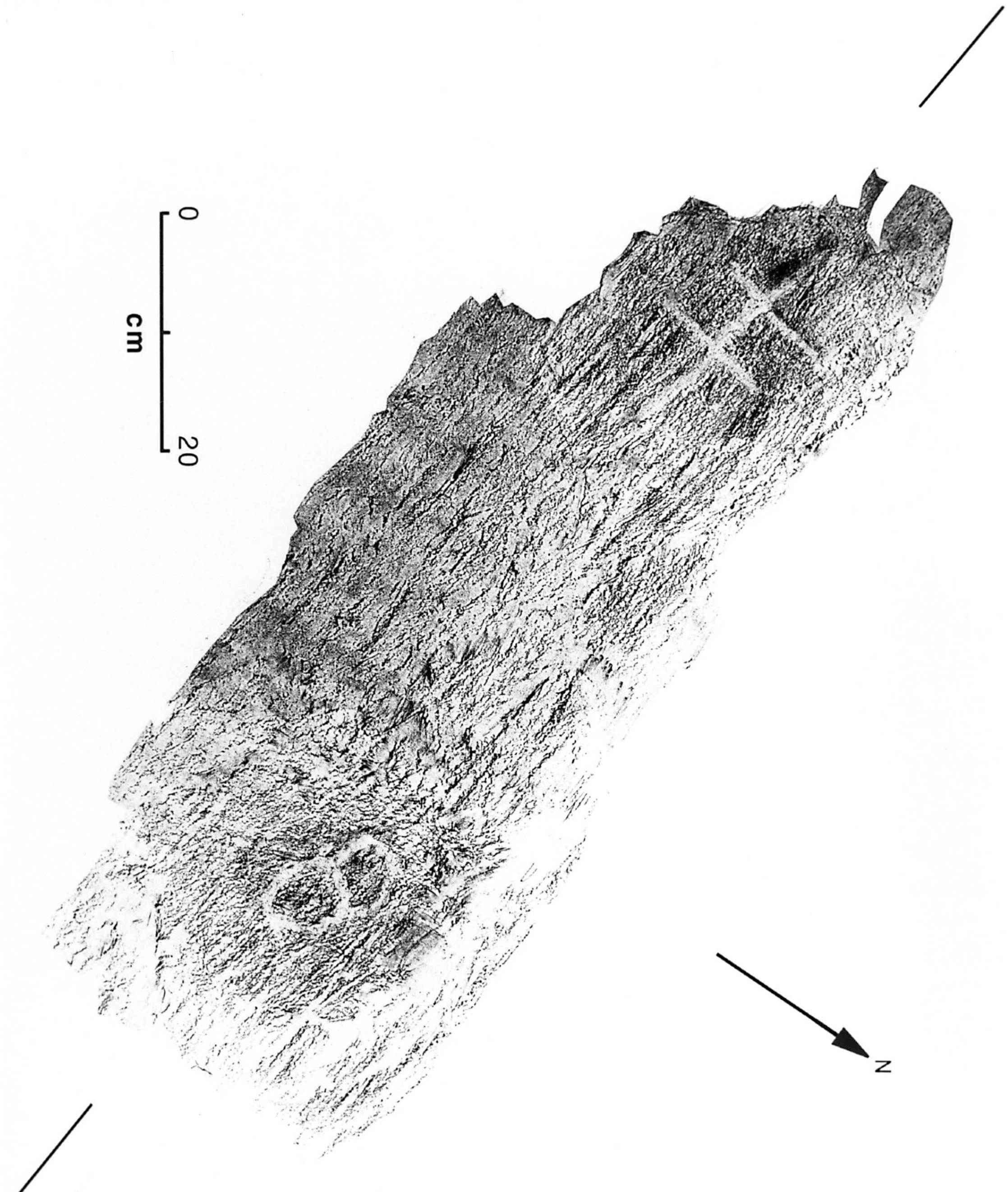

Figure 23. Graphite rubbing of the petroglyph panel at site MFN. The line segments indicate the direction of the sunrise point on the eastern skyline at the equinox.

petroglyph consists of two adjoining and slightly overlapping circles. The circular nature of these symbols is best seen by tracing the outline of the (very slightly lighter colored) individual peck marks in Figure 24b since some exfoliation of the rock surface has occurred, particularly along the south side of the symbol.

Let us consider first the two circles. These circles are similar in size and line width to the two exterior circles in the central section of the panel at MFM which, as discussed above, appear to be moon symbols. This suggests that the MFN circles are also moon symbols. Placed in contact, they would appear to indicate a unit of time consisting of two moons. Placing them in contact also avoids confusing them with the symbol for eyes or looking, which consists of two circles a short distance apart (Martineau 1973:19). As indicated above, the MFN panel, being located on a sloping surface, has an up and a down direction. According to Martineau (1973:39–40), the upper left petroglyph of a panel precedes the one at the lower right. Thus, the MFN panel reads: After . . . (something–depicted by the double cross petroglyph), two moons. Or, Two moons after . . . (something).

We therefore ask: does some event occur at this site two moons (lunations) after something else? In fact, it does. Calculation and direct observation show that on August 19 (or 20, depending on the four-year cycle) at precisely two moons ($59\overset{d}{.}06$) after the summer solstice, the sun, as seen from the observer's seat at MFN (described below), rises just slightly north of the center of Cathedral Rock, discussed in the previous section. This sunrise is quite spectacular, as can be seen in Figure 26 which reproduces a photograph of the sunrise on August 19, 1998. On this occasion, the declination of the sun at sunrise, which occurred at $06^{\rm h}\ 16^{\rm m}\ 16^{\rm s}$ PST, was $\delta_\odot = +12°42\overset{\prime}{.}93$. At exactly two moons after the solstice, $\delta_\odot = +12°41\overset{\prime}{.}94$ (in 1998). Thus in 1998, the sun rose at an azimuth only $1\overset{\prime}{.}28$ north of its position when sunrise occurs exactly two moons after the solstice.

The panel would therefore appear to read: "Two moons after the solstice." There would be no doubt in the reader's mind as to which solstice was meant; as discussed above, no one was present two moons after the winter solstice.

This interpretation would indicate that the upper left petroglyph—in the shape of a double cross—is an ideograph representing the solstice. This seems reasonable since to the Indian observer the two solstices divided the year (indicated by the east-west line) into two parts. In one part, the sunrise (and sunset) point was moving northward along the horizon or skyline, while in the other it was moving southward.

That this petroglyph, and indeed the entire panel, does have some relation to the motion of the sun or sunrise point during the year is further suggested by the fact that the axis of the double cross and a line through the double cross and two-moon symbols are both aligned approximately with the direction of the equinox sunrise. This direction is indicated by the line segments at either end of the rubbing reproduced in Figure 23. That direction was established by photographing the equinox sunrise and then adjusting two plumb lines to align with the observed sunrise point. The points of intersection of the plumb lines with

Figure 24. Photographs of the elements of the petroglyph panel at MFN shown in Figure 23. Illuminated by early morning sun. Top (24a): Upper left petroglyph. North at the top. Bottom (24b): Lower right petroglyph. Northeast at the top. Scale bars = 10.0 cm.

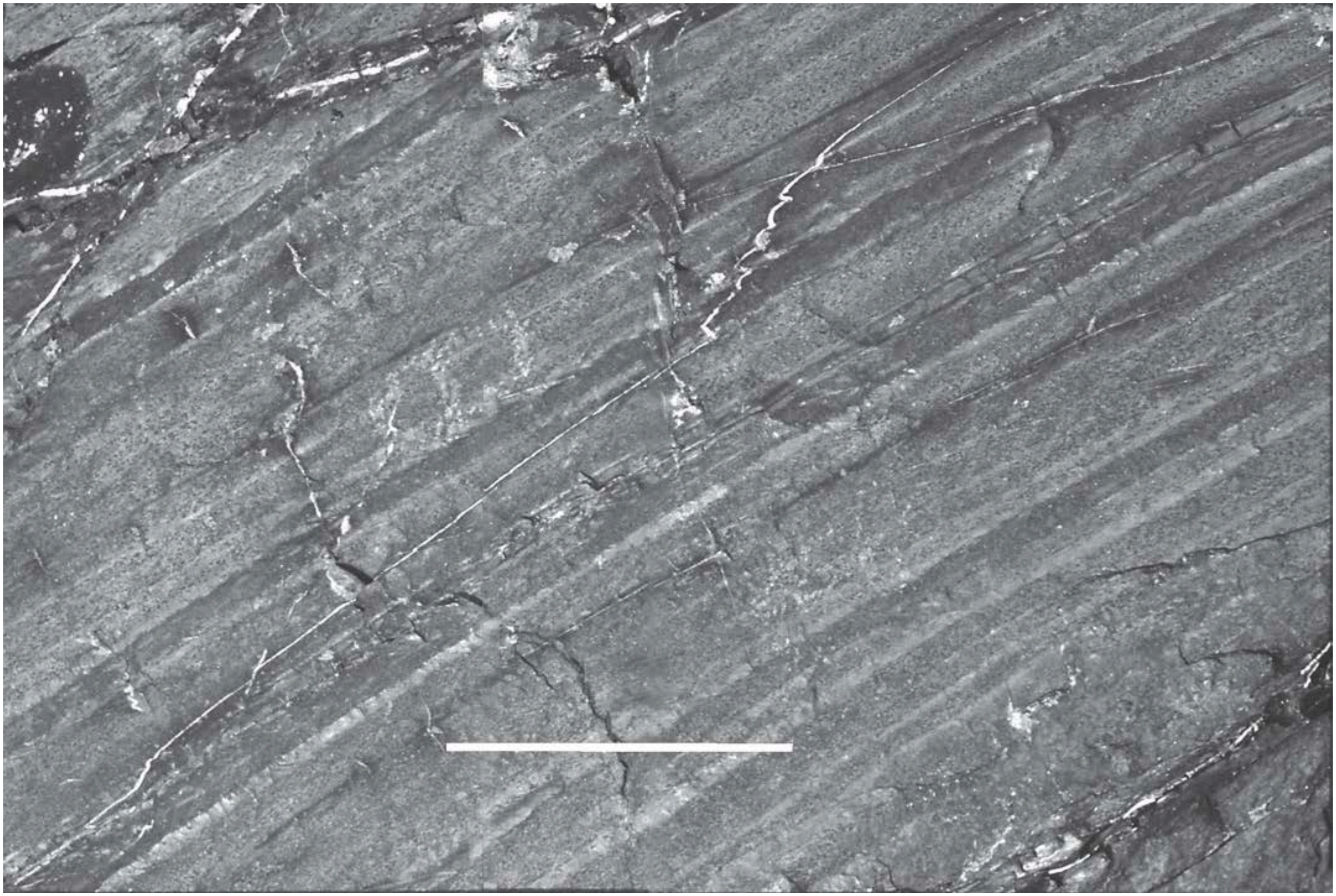

Figure 25. Photograph of lower portion of petroglyph panel at MFN, northeast at the top. Lower right petroglyph (Figure 24b) is located left of center. Gortner's possible third petroglyph is visible just below and to the right of center. Scale bar = 20.0 cm.

the bedrock surface were then marked on a rubbing of the petroglyph panel lying in place on the panel. The azimuth of this line was then determined by placing a compass on the rubbing and marking the north direction on it, assuming a magnetic declination of $A_{\rm m} = 16°$. The resulting observed azimuth of the equinox sunrise point is $A = 98° \pm 1°$, in good agreement with the calculated value $A = 97°31'$, derived using the skyline altitude $h = 9°29'$ measured on a photograph of the eastern skyline as seen from MFN, and correcting for refraction as discussed above. In comparison, the azimuth of that portion of the double cross petroglyph lying between the two cross marks is $A = 103°$, while the azimuth of a line through the double cross symbol and tangent to the south side of the lower circle is $A = 98°$. A line through the double cross symbol and bisecting the two circles has $A = 95\frac{1}{2}°$and a line through the double cross symbol and the north side of the upper circle has $A = 91°$.

In this connection, it is of interest to consider how the Indian observer might have determined the date of the equinox. It would appear that this could have been done in three different ways:

(1) By finding the midpoint between the positions of the sunrise (or sunset) points at the solstices. To do this accurately would require having an observing site with a flat, unobstructed horizon from the summer to the winter solstice sunrise (or sunset) points, and would necessitate regular observations from that site throughout the year. Such observations were probably not possible for the writers of the Middle Fork petroglyphs, owing to the mountainous terrain and their seasonal migrations.

(2) By observing the diurnal path of the shadow of the tip of a gnomon. As discussed in Part One, at the equinox, when $\delta_\odot = 0°\,00'$, the tip of the shadow of a gnomon will trace, on a flat, level surface, a straight line from west to east during the day. When $\delta_\odot \neq 0$, the shadow tip traces a curve which (in the northern hemisphere) is convex toward the south when $\delta_\odot < 0$ and toward the north when $\delta_\odot > 0$. These curves and the line at the equinox are distorted slightly by the daily motion of the sun in declination which, near the autumnal equinox is now $\Delta\delta_\odot = -23'.4$/day. By observing within a few hours of the sun's meridian passage, this motion amounts to no more than about $8'$–$10'$ during the observations. Measurement of the tip of a gnomon's shadow is generally considered to be rather inaccurate, owing to the diffuseness of the shadow-tip resulting from the angular diameter of the solar disk. However, as discussed in Part One, this inaccuracy can be overcome and measurements of considerable precision obtained by replacing the tip of the gnomon with a sphere. Since the diffuseness of the elliptical shadow of the sphere is everywhere the same, the center of the

Figure 26. Sunrise at MFN on Two-Moon Day, as seen from the observer's seat. Photograph taken 1998 August 19 at 06:16:16 PST. Sunrise azimuth is $1\overset{\prime}{.}28$ north of its value when the sun rises exactly two lunations after the summer solstice. Photograph on Kodachrome 64, 50 mm focal-length lens, exposure 1/250 sec at f/11. The lower view is an enlargement of the central section of the photograph, showing Cathedral Rock.

shadow can be located quite accurately by visual inspection. Experiment shows that even using a very small gnomon, it is possible to determine the time of the equinox with an error of less than $0\overset{\mathrm{d}}{.}2$ (see Part One). Owing to its simplicity and accuracy, this is presumably the method that would have been employed *if* the use of the gnomon was understood.

(3) By using day counts. The date of the equinox can be approximated by dividing the interval between the preceding and following solstices by two. Owing to the ellipticity of the earth's orbit about the sun and to the change in the spatial orientation of that orbit with time, the seasons are not of equal length, and these lengths vary with time, as shown in Part One (Appendix 2, Table A1). At present (A.D. 2000) the date of the autumnal equinox derived from the day count from the summer solstice is $-2\overset{\mathrm{d}}{.}0$ earlier than the true equinox. In the past, that error was the same or slightly smaller, amounting to $-2\overset{\mathrm{d}}{.}0$ in A.D. 1000, $-1\overset{\mathrm{d}}{.}9$ in A.D. 01, $-1\overset{\mathrm{d}}{.}6$ in 1000 B.C. and $-1\overset{\mathrm{d}}{.}2$ in 2000 B.C. At MFN, the daily motion of the sunrise point at the time of the autumnal equinox is presently $\Delta A = +30\overset{\prime}{.}8$/day, so that using day counts now results in an error of $\Delta A = -62'$ in the azimuth of the sunrise point. In earlier times, the daily motion of the sunrise point was slightly greater owing to differences in both the obliquity and the spatial orientation of the earth's orbit. Consequently, the error in the azimuth of the equinox sunrise point calculated from day counts was $\Delta A = -62'$ in A.D. 1000, $\Delta A = -60'$ in A.D. 01, $\Delta A = -52'$ in 1000 B.C. and $\Delta A = -43'$ in 2000 B.C.

The orientation of the axis of the double cross symbol agrees best with the true equinox sunrise direction, while the alignment of this symbol with the two-moon petroglyph agrees best with the direction given by the day counts. Clearly, the various uncertainties are too great to permit us to conclude which of these two methods might have been used to determine that direction.

That the sunrise over Cathedral Rock was the event being observed at MFN is further suggested by two rocks, shown in Figures 27, 28 and 29, arranged so as to form a seat with a back. Measurement of these rocks suggests that they may have once been part of the same glacial erratic boulder, and were split apart by frost wedging. If so, that split occurred a very long time ago, as the split surfaces—the top side of the seat and the front side of the back—are now much weathered. This seat is located 5.4 m (17 ft 10 in) N 27 1/2°E of the petroglyph panel, and is about 4.6 m (15 ft) from the north end of the top of the bedrock outcrop. It is perched rather precariously on the northeast edge of the top of the outcrop, as can be seen in the lower section of Figure 29. It appears unlikely that the present configuration of the two rocks could have resulted simply from the

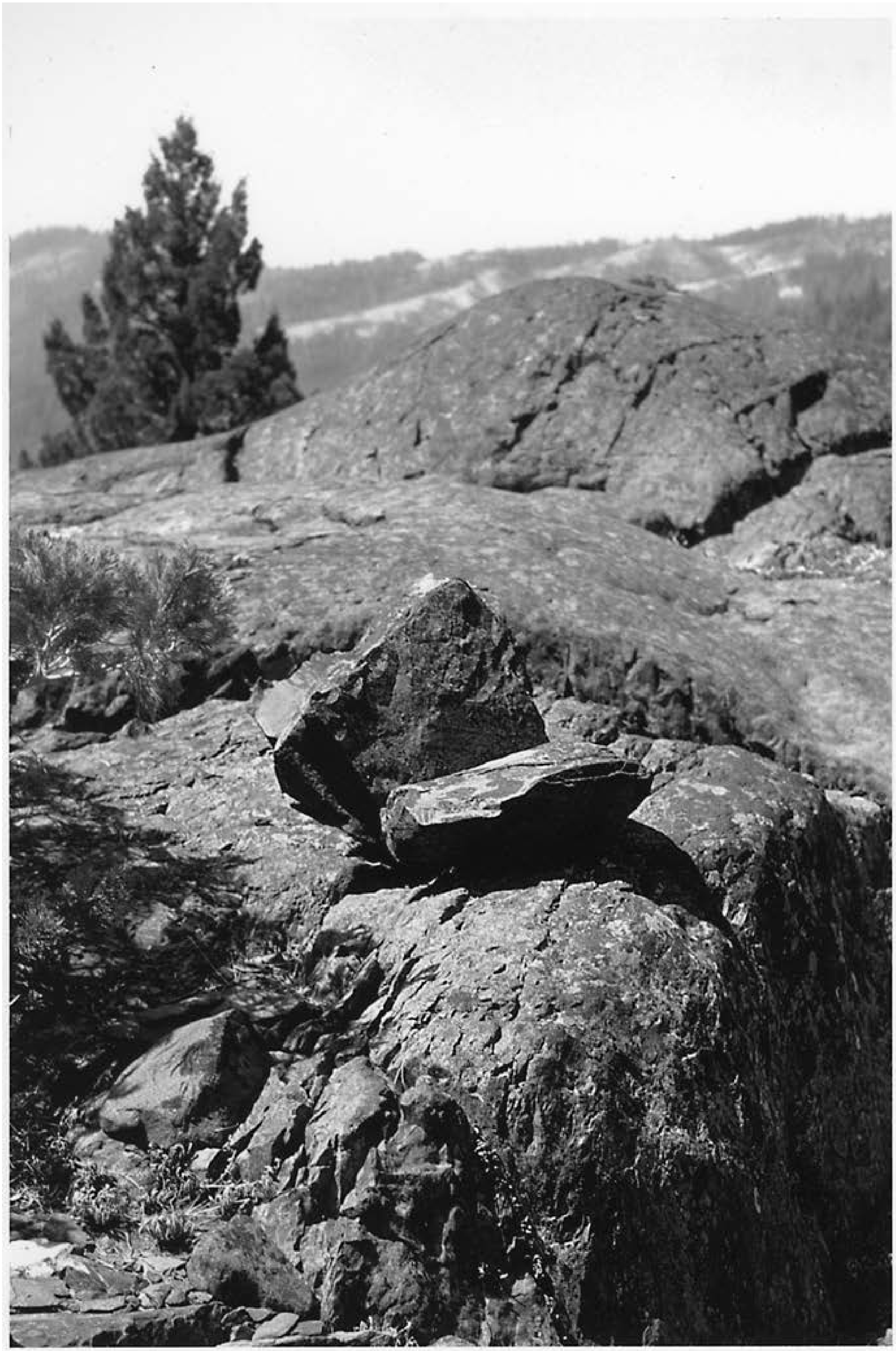

Figure 27. Observer's seat at MFN, looking west.

in situ splitting of a pre-existing boulder. The shape of what is now the bottom side of the seat would have caused this piece to roll away from the piece that now forms the back, and if the splitting had occurred at the present location of the rocks, the seat portion would very likely have fallen off the edge of the platform on which it now rests. It appears, therefore, that the two rocks were moved into their present location and configuration. That this movement took place a long time ago is demonstrated by the fact that frost wedging has caused splitting of the rock forming the back of the seat, as can be seen in Figure 28b, which shows the rear side of this rock. Here, the split surfaces are much less weathered than the surfaces of the seat and the front of the back. Nevertheless, some weathering of the more exposed upper surface of the split off portion has occurred, and lichen growth has taken place on both of the split surfaces. Thus, this split is clearly some hundreds of years old, and at least the rock forming the back of the seat has been in its present location since before that time.

The horizontal surface of the seat itself is 51 cm (20 in) wide and 43 cm (17 in) deep and is 24 cm (9.5 in) above local ground level. The back of the seat rises 41 cm (16 in) above the top surface of the seat. Immediately in front of the seat the bedrock drops steeply about 1.2 m (4 ft) to a lower ledge. The azimuth of the front surface of the back of the seat is difficult to measure accurately but appears to be $A \simeq 346°$, so that the seat faces $A \simeq 76°$. The azimuth of Needle Peak is $A = 75°$, and of Cathedral Rock is $A = 82°$. However, owing to the compound angles of the seat and its back, the observer sitting on the seat finds himself facing directly towards Cathedral Rock, rather than Needle Peak. This orientation suggests that what was being observed was indeed the sun rising over Cathedral Rock. The Needle Peak sunrise might also have been observed to confirm the day count from the solstice, as discussed in the previous section, or to begin the count-down to the date of the Cathedral Rock sunrise. (Note that at MFN, the alignment of the sun with Needle Peak occurs approximately $1\overset{\mathrm{d}}{.}5$ earlier than at MFM; this value is somewhat uncertain, being derived from observations on only two days in 2004.)

The geometry of the Cathedral Rock sunrise as observed from the Observer's seat is shown in Figure 30. The figure shows Cathedral Rock and the eastern skyline traced from a photograph. The horizontal line is an arbitrary level line, while the inclined solid lines mark the path of the center of the solar disk at one-day intervals, day zero being the path when the sun rises exactly two moons ($59\overset{\mathrm{d}}{.}06$) after the summer solstice. The circle indicates the disk of the sun ($32'$ in diameter) and the dots at the ends of the inclined lines show the position of the center of the solar disk at the moment the upper limb of the sun appears above the skyline. The two dotted lines indicate the extreme positions of the sun's center at the two-moon sunrise in the four-year leap-year cycle. As Figure 30 shows, the daily motion of the sunrise point along the skyline is fairly large ($\Delta A = +25\overset{\prime}{.}2$/day at present), so that the date of the two-moon sunrise is determined unambiguously. Note, however, that the exact location of the two-moon sunrise

Figure 28. Observer's seat at MFN. Top (28a): Looking west. Bottom (28b): View of rear side of seat, looking east. Shows splitting of back of seat due to frost wedging.

Figure 29. Observer's seat at MFN. Top (29a): Looking northwest. Bottom (29b): Looking south. Tape calibrated in inches.

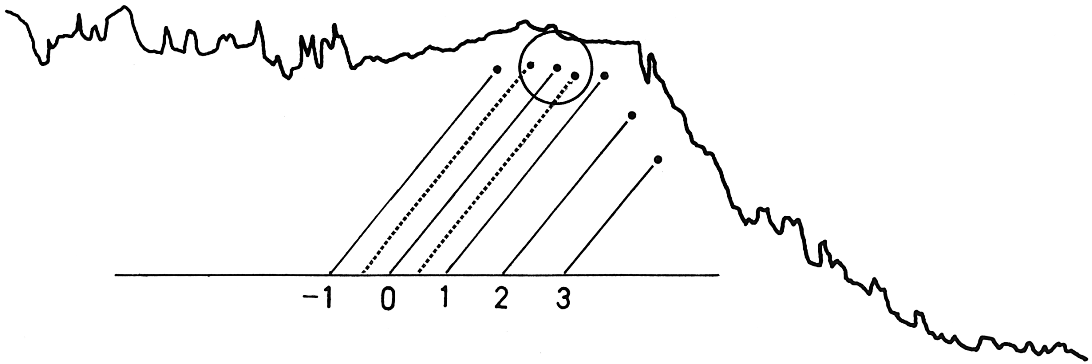

Figure 30. Geometry of Two-Moon Day sunrise at MFN, as seen from the observer's seat. The figure shows Cathedral Rock and adjacent skyline traced from a photograph taken at the observer's seat. The horizontal line is an arbitrary level line. The inclined solid lines show the path of the center of the solar disk on successive days. Day zero is the date when the sun rises exactly two lunations after the summer solstice. The dotted lines indicate the range in position of the two-lunation sunrise path due to leap year. Dots at the ends of the inclined lines show the position of the center of the solar disk when the upper limb first appears above the skyline. The circle indicates the solar disk, $32'$ in diameter, at the two-lunation sunrise.

point along the top of Cathedral Rock depends rather critically on the position of the observer; moving the observing point along a line perpendicular to the line of sight to Cathedral Rock by .58 m (1.9 ft) changes the location of the sunrise point by one arc minute.

Defining the edges of the top of Cathedral Rock as in the preceding section, Figures 26 and 30 show that, as viewed from the observer's seat, the sunrise point in 1998 was about $S = 6'.8$ north of the center, and $\Delta A = -6'.9$, since the altitude of this point is $h = 10°24'$. Thus, the two-moon sunrise was centered when the declination of the sun was $5'.2$ south of its value in 1998, or $\delta_\odot = +12°37'.7$. Owing to the changes in the obliquity and longitude of perihelion of the earth's orbit with time, the solar declination two moons after the summer solstice varies with epoch as shown in Table 5, where $\delta_{\odot 2☾}$ was calculated using values of $\delta_\odot$ derived from the JPL Ephemeris Program (Giorgini et al. 1996). This table shows that as seen from the observer's seat, the two-moon sunrise point was exactly centered over the top of Cathedral Rock in about 400 B.C. This date is in good agreement with what is known about the ancient inhabitants of the region. As discussed in Section 2, above, the archaeological evidence indicates that the petroglyphs at MFM and MFN were inscribed by the Martis Complex Indians, who occupied the area from about 2000 B.C. to around A.D. 500. Note that the location of the seat is not constrained by the geometry of the site; a fairly wide range of north–south positions could have been used, strengthening the supposition that the precise location was chosen to make the two-moon sunrise appear centered over Cathedral Rock.

The present two-moon sunrise path at MFM is shown in Figure 22. As seen

Table 5. Solar Declination at Mid-Season ($\delta_\odot = + \epsilon/2$) and Two Moons after Summer Solstice.

Epoch year	Solar Declination at: Mid-Season $+\epsilon/2$[a]	Two Moons after Summer Solstice[b]	Difference in Dates $(+\epsilon/2)-2_☾$
+2000	+11°43.′17	+12°41.′94	+3.ᵈ02
+1000	+11°47.′07	+12°43.′70	+2.ᵈ81
+ 01	+11°50.′85	+12°41.′57	+2.ᵈ68
−1000	+11°54.′42	+12°32.′19	+1.ᵈ81
−2000	+11°58.′18	+12°26.′12	+1.ᵈ53
−3000	+12°00.′63	+12°15.′34	+ .ᵈ68

[a] Using values of ϵ listed in Part One (Appendix 2).
[b] Using values of $\delta_\odot$ derived from JPL Ephemeris (Giorgini et al. 1996)

from this site, the two-moon sunrise now occurs well to the north of Cathedral Rock, but (as indicated by Table 5) was centered over it in about 5000 B.C. However, this date is well before the advent of the Martis Indians in the region.

Southeast of the MFN petroglyph panel, and at a slightly lower elevation, is a flat area with numerous rectangular glacial erratic stone blocks which could have been used as a viewing area where as many as 25–50 people could assemble to watch the two-moon sunrise. The largest of these blocks, at the west end of this area, is about 14 m (45 ft) southeast of the panel.

Why would it have been important to observe and celebrate Two-Moon Day? It will be noted that this day now occurs just three days earlier than mid-season day (when $\delta_\odot = +\epsilon/2$), discussed in the previous section. In the past, these dates were even closer together, as detailed in Table 5. Most likely, Two-Moon Day would have been observed for the same reason as mid-season day. That is, to fix the date for a ceremony to mark the time of midsummer, similar to the ancient British mid-quarter day celebrations discussed above. Two-Moon Day, presently August 19 or 20, falls about half way between the time, presumably about the middle of June, that the area was first reoccupied after the melting of the winter snows, and the time of departure on October 19, as fixed by the panel at MFM.

As discussed in the previous section, mid-season day was very nicely marked by the Cathedral Rock sunrise at MFM; when $\delta_\odot = +\epsilon/2$ the sun rose above the middle of Cathedral Rock in about 2000 B.C. MFM would thus have been ideally suited for observation of this event, at least at the beginning of the Martis Complex occupation. Yet, the evidence from MFN suggests that Two-Moon Day—at that time only about two days earlier—was observed instead.

A possible explanation is provided by a petroglyph at site CA–SBR–291, in the Providence Mountains of southern California, discussed in Part One. As has been described by Rafter (1985:109), there is at this site a rock overhang with an aperture in the top through which a ray of sunlight falls, near midday, onto the interior surface of the cavity. When $\delta_\odot = +\epsilon/2$, this ray takes the form of a narrow finger or arrow of light which passes through the center of a circle pecked into the surface of the overhang, showing that at least one Indian group was interested in mid-season-type observances. A more detailed study by the writer, reported in Part One, shows that at present, the ray exactly bisects the circle only when the solar declination is precisely $\delta_\odot = +\epsilon/2$ at the time of bisection. From the geometry of the event, it is clear that the petroglyph had to have been inscribed within about the last 500 years. Thus, the use of $\delta_\odot = +\epsilon/2$ to define a mid-season event may be a fairly recent innovation. If so, then the observance of Two-Moon Day at MFN might reflect an older tradition or method of determining a date that served the same purpose as the mid-season or mid-quarter days, and which was employed before the idea of using $\delta_\odot = +\epsilon/2$ had originated.

As mentioned in the previous section, a second site in southern California may provide further evidence that at least some Indian tribes observed a mid-season day event. According to Hunter and Rafter (1985:151), site CA–RIV–61 in Mockingbird Canyon, Riverside County, consists of several large granitic boulders that form two natural shelters. Within one of these (Spring Shelter), near sunset at the winter solstice, a ray of sunlight bisects a red disk pictograph on the north wall of the shelter. At the equinox, the sun, as seen from this shelter, sets in a deep "U"-shaped notch on the horizon, and at the summer solstice sets on the top of a large boulder which sits atop a small hill. When $\delta_\odot = +\epsilon/2$, the sun sets with its southern limb just tangent to the north side of a boulder on the horizon. Thus, the site could have been used to determine mid-season day, although the evidence is not as compelling as at CA–SBR–291. Since the solstice alignments are precise today, they were not precise in earlier times owing to the changes in the earth's orbit with time, as discussed above. It follows, then, that the site was used for solstice observations (and the winter solstice pictograph was painted) only relatively recently, perhaps within the last 500–1000 years. A more precise dating of the winter solstice pictograph could probably be obtained by determining the solar declination at which the ray of sunlight no longer appears to exactly bisect the painted disk. If the site was used to determine when $\delta_\odot = +\epsilon/2$, then again it was used for this purpose only relatively recently. As noted above, when $\delta_\odot = +\epsilon/2$ the setting sun is now just tangent to the north side of the horizon boulder, and in the past would have set some distance to the north of that boulder.

Observations of Two-Moon Day might also have been possible at this site. According to the sketch published by Hunter and Rafter (1985), the sun on Two-Moon Day now sets with its north limb more or less tangent to the south side of the horizon boulder. Table 5 shows that the solar declination on Two-Moon Day has remained close to its present value since about A.D. 0. Precise observations of the two-moon sunset would be required in order to determine whether the site could actually have been used to mark the date of Two-Moon Day.

5

Later Use of the Sites

As discussed in the preceding sections, the patination of the petroglyphs, the spacing of the two moon symbols at MFM, and the location of the observing seat at MFN all suggest that both sites were established and used in the period from about 400 B.C. to A.D. 01. It appears possible, however, that some use of both of the sites may have occurred as late as the mid eighteenth or early nineteenth centuries.

At each of the two sites there are the remains of a large Western Cedar that appears to have been felled by being burned at its base. These trees grew out of the bedrock on the knolls and were surrounded by little or no vegetation, making it difficult for a forest fire to approach them with sufficient intensity or duration to burn a large ground-level cavity in one side of an otherwise healthy tree. These trees, when upright, were located where they might have interfered with observations of Departure Peak from MFM, or Cathedral Rock from MFN.

The tree at MFM is fairly well preserved, having fallen across rocks and another tree which hold its trunk up off the ground at its lower end. Tree ring dating (Rex Adams, personal communication 2012) gives an inner date of A.D. 1424p and an outer date of A.D. 1742vv++. The inner date is that of the pith ring, so that the tree germinated only a few years prior to 1424. The outer date is that of the last (sapwood) ring. However, the outer surface of the trunk has been eroded away so that some sapwood rings have been lost. Between 60 and 70 sapwood rings still exist. Cores of living Western Cedars growing nearby indicate that there are typically about 75–120 sapwood rings. Thus the tree died sometime in the interval from shortly after 1742 to as late as about 1802, before the intrusion of the Europeans into the region.

At MFN, the available tree sample is much poorer, being from a section of root just below ground level. According to Adams (Rex Adams, personal communication 2012), the inner date of this sample is A.D. 1553, while the outer date is A.D. 1754vv++. The inner rings of this sample are missing so that while the tree germinated some time before 1553, the precise date can not be determined. The outer date is that of the last remaining (heartwood) ring. No sapwood remains, and the number of missing heartwood rings is unknown. Using the number of sapwood rings from nearby living trees, the death date of this tree is therefore likely to be no earlier than about 1829, and possibly as late as about 1874, and thus may or may not predate the arrival of the Europeans.

It is not absolutely certain that these trees were felled by artificially set fires. Consequently, their remains can only be regarded as possibly suggestive of at least sporadic use of the sites by the Indians as late as the mid eighteenth or nineteenth centuries.

6

Evidence from a Nearby Site

Support for certain of the conclusions set forth in the preceding sections may be provided by a petroglyph panel at a site near MFM and MFN. This site is FS 05–17–54–416 which, for simplicity, will be referred to henceforth as Site 416. Since the panel at Site 416 is not related to astronomical events or observations, its interpretation is much less certain that those of the panels at MFM and MFN, discussed above.

As shown in Figure 1, Site 416, indicated by a cross, is located some 500 m (1640 ft) east of MFM. Like MFM and MFN, the site is on the top of a bedrock outcrop, smoothed and polished by glacial action, which rises about 30 m (100 ft) above the valley floor. There are a number of petroglyphs at this site. The main panel is located on the top surface of the outcrop, as shown in Figure 31, and consists of three elements, as shown in Figure 32. This figure reproduces a rubbing of the panel, made using tombstone wax and with no enhancement of the grooves of the petroglyphs. The petroglyphs are therefore less distinct in this rubbing than in those shown in Figures 3 and 23, and the fainter, less heavily pecked portions are less visible here than they are visually or on photographs taken with a low sun angle. This is illustrated in Figure 33, which reproduces a photograph of the uppermost petroglyph in Figure 32 as illuminated by the late afternoon sun.

The form of this petroglyph is somewhat uncertain. Seen visually, this uppermost petroglyph has the appearance of the track of the hind foot of a bear, crossed by a single transverse line, but a track whose outline is not complete, being interrupted by a gap between the claws and the transverse line, and in which the rear section, behind that line, is very lightly pecked, as is the right half of the transverse line. These lightly pecked sections are more heavily patinated than the remainder, suggesting that, if real, they predate the other, more deeply incised portions. Alternatively, if we suppose that the lightly pecked rear section is not real but only the chance arrangement of naturally occurring pits in the rock surface, the petroglyph becomes a transverse line with four forward-projecting claws, followed by a second symbol consisting of a line with a 90° bend.

If we suppose that the petroglyph is that of an interrupted bear track with a

Figure 31. Site 416, looking southeast. Rubbing of petroglyph panel in place.

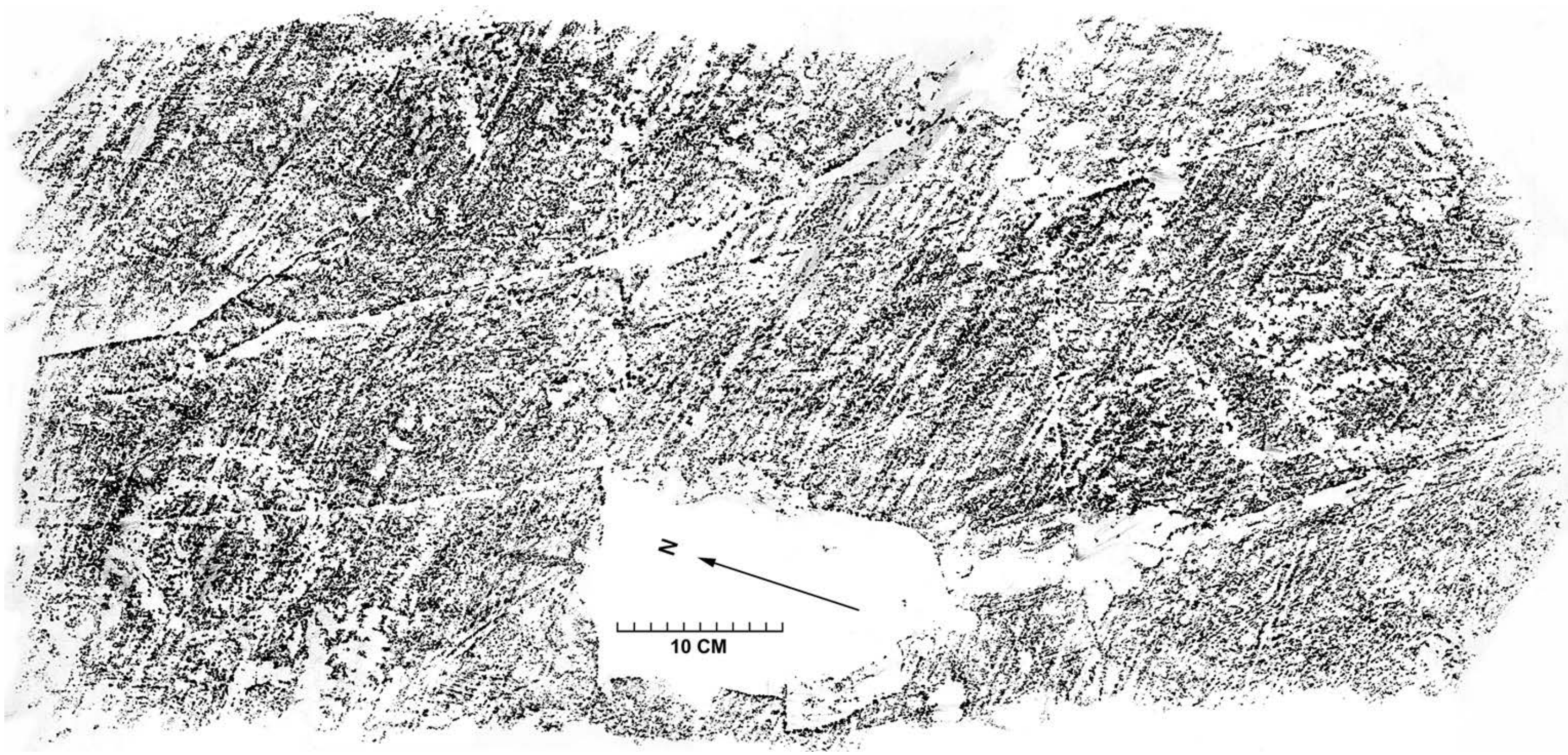

Figure 32. Tombstone-wax rubbing of the petroglyph panel at Site 416. East–northeast at top, south–southeast at right.

transverse line, then we might interpret it as follows: At the large petroglyph site (FS 05–17–57–05; CA–NEV–4) above Donner Lake, the uppermost petroglyph is that of the track of the hind foot of a bear. This track has a transverse line across its middle. From the location of the track, the top of Donner Pass is visible, and the bear track points toward that point along the ridge line where the present highway crosses over the pass. The terrain near the top of the pass has been altered by highway and railroad construction. However, it seems likely that originally the easiest crossing of the pass was at the site of the present highway. This suggests that the bear track was designed as a trail marker. Whereas the track of the front paw of a bear was used (at MFM) as the reference point for a line of sight, the rear-foot track invites us to follow where the bear has "gone," i.e., it indicates a trail or direction, while the transverse line across the track indicates that the trail crosses over a ridge line of the mountain. Such a marker may have been needed at this location since, to a traveler standing at the petroglyph site, the quickest ascent to the pass *appears* to be straight up the streambed of Donner Creek to its headwaters and then on up and over the ridge. In fact, the final ascent to the ridge by this route is quite steep, and it is very possible that a route up the slope on the north side of Donner Creek to the present road crossing was significantly easier.

If, then, a bear's hind-foot track with a transverse line indicates the direction to a ridge crossing, the bear track at Site 416 might indicate the direction to the point where the trail from Picayune Valley crosses over the ridge line between that valley and Five Lakes Valley to the east, enroute to the eastern slope of the Sierras. As shown by Figure 31, the bear track is located just north of a large, glacially deposited erratic boulder and points to the south wall of the Middle Fork Valley. The azimuth of the axis of the track was measured with a compass, using three different features of the track:

(1) The compass was aligned along the estimated longitudinal axis of the entire track. This gave $A = 143\overset{\circ}{.}5$.

(2) The compass was aligned 90°to the front line of the track, i.e., the line forming the base of the claws or toes. This gave $A = 137\overset{\circ}{.}8$.

(3) The compass was aligned 90°to the direction of the transverse line which crosses the middle of the bear track. This gave $A = 139\overset{\circ}{.}8$.

The mean of these three measures is $A = 140\overset{\circ}{.}4 \pm 1\overset{\circ}{.}8$. In deriving these values, the azimuth of magnetic north was assumed to be $A_{\mathrm{m}} = 15\frac{1}{2}^\circ$. Since all measures were made on the same day (October 12, 2001), there is, in addition, the possibility of a systematic error in them of up to about ±1°, owing to the effect of any magnetic storms that may have been in progress at that time.

The topographic map gives a value for the azimuth of the pass between Picayune Valley and Five Lakes Valley, as seen from Site 416, of $A = 142\overset{\circ}{.}6 \pm\overset{\circ}{.}1$, the un-

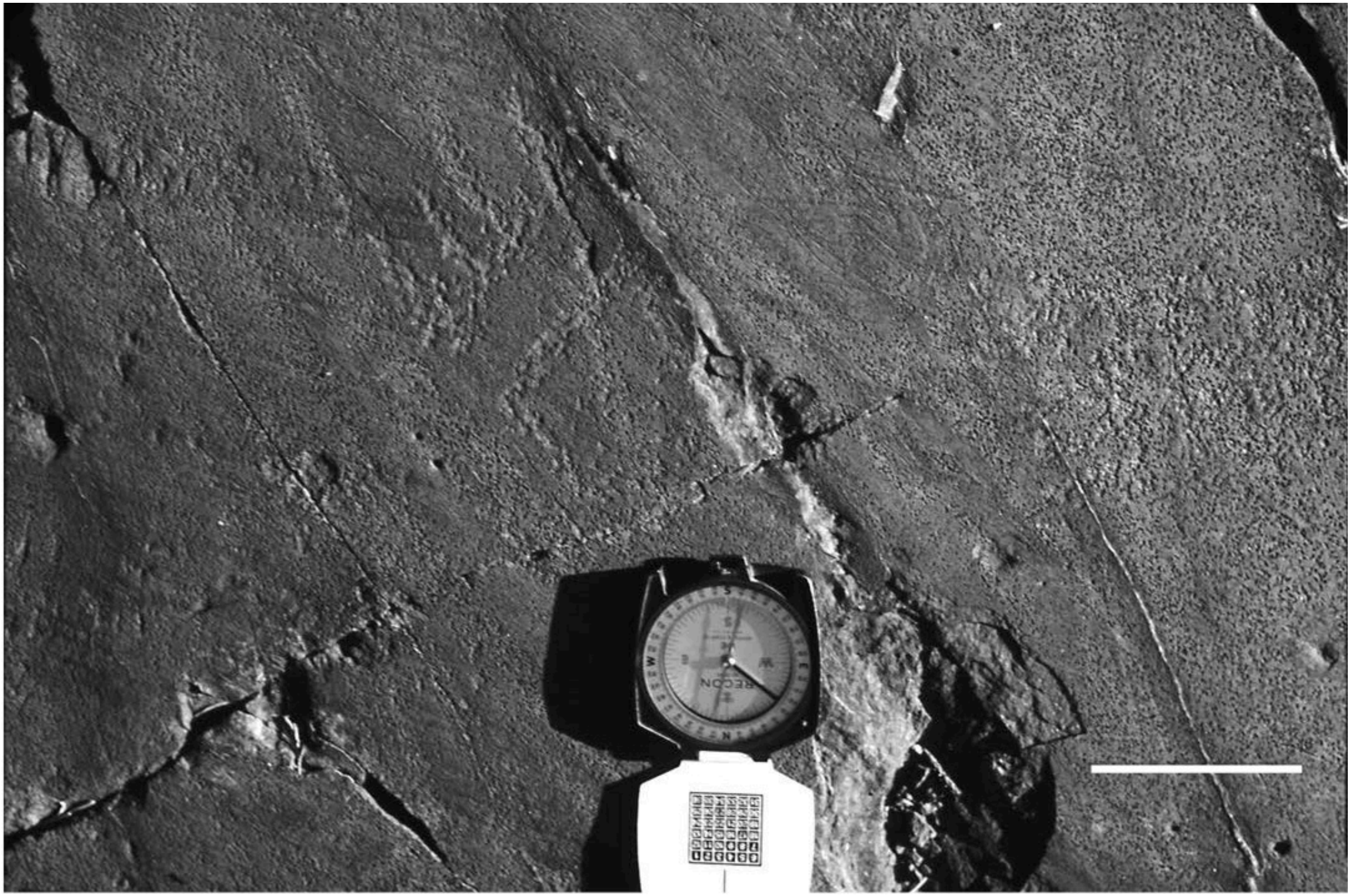

Figure 33. Photograph of the bear track at Site 416, as illuminated by the late afternoon sun. Scale bar = 10.0 cm.

certainty being derived from the repeat measures of the map. The actual error is probably somewhat larger, owing to errors in the location of Site 416 and of the map itself.

Overall, the alignment of the bear track to the direction of the pass is quite good. As shown by Figures 1 and 31, the pass itself, near the south end of Picayune Valley, is not visible from Site 416 owing to the intervening ridge which runs down in a northeasterly direction from the ridge line on the south side of the Middle Fork valley. The direction of the pass could, however, have been laid out with considerable precision, in the manner outlined above for the going out petroglyph at MFM. Similarly to MFM, the location of the bear track just to the north of the large boulder, as shown in Figure 31, might indicate that this boulder was used as the rearward reference marker by the survey team on the ridge.

The alignment of the bear track to the pass would appear to support the conclusion that this symbol indicates the direction of the trail over the ridge line. The fact that the track is not complete—or interrupted—could indicate that one can not go to the pass directly; the way is interrupted by the intervening ridge. The bear track appears to mark the "top" of the panel, so that we are to read it while facing in the direction indicated by the track, i.e., towards the pass. Coming down the panel, the next element is a right-angle petroglyph, visible near the left-hand edge and below the center of the rubbing reproduced in Figure 32. This symbol has the meaning: "turn" (or "go around") "to the right" (Martineau 1973:20–21). The next element, to the right and below the right-turn symbol, in the lower right-hand corner of Figure 32, is a spiral, unwinding counterclockwise. This symbol has the meaning: go up (Martineau 1973:18–19). Note that this spiral does not end on top of itself. Ending on top of itself would indicate going up to the highest point of something (Martineau 1973:20–21). Thus, the spiral indicates: go up, but not to the top of the highest point or, in other words, go up to a lower point, i.e., a pass. Since a symbol to the left and above is to be read as preceding a symbol to the right and below (Martineau 1973:39–40), these two symbols read: first turn to the right and then go up (to a pass). The entire panel thus describes the trail from Site 416 up the Middle Fork and Picayune Valleys and on over the ridge line towards the eastern side of the Sierras:

> "The trail across the ridge line is in this direction, but the way is interrupted. First turn to the right, then go up to the pass."

These instructions accurately describe the present day (and presumably the original) trail: One ascends the Middle Fork to the confluence of Picayune Creek, turns right up Picayune Valley, and then goes up and over the pass. When, today, the traveler ascends the present trail up out of the Middle Fork Valley to the point where the Picayune Valley first comes into view, the pass is seen directly ahead, appearing as the lowest point on the skyline, as shown in Figure 34. As the figure shows, from this vantage point the pass appears to be exactly at the head of Picayune Valley, and is the outstanding feature of the southern skyline.

Thus, the description given by the panel is quite adequate; the traveler, having reached this point, would see clearly where he was supposed to go.

The location of such a trail marker at Site 416 is also quite logical. This site is the last one near the valley floor from which, as one ascends the Middle Fork, the upper reaches of the Middle Fork Valley can still be seen. Even here one does not see the actual ridge line above the headwaters of the Middle Fork, but only the bare bedrock slope below that ridge. From this location, one has the impression that the best way to cross to the east side of the range is simply to proceed up the Middle Fork all the way to the ridge. However, as discussed earlier, eastward from Picayune Valley the Middle Fork canyon becomes very steep and difficult to traverse; it is much easier to go up Picayune Valley, over the pass near its southern end, and on across the head of Five Lakes Valley in order to reach the eastern slope. Site 416 is therefore a logical place to inscribe a warning sign directing the traveler to take the longer route up Picayune Valley instead of attempting the ascent of the Middle Fork itself.

If the bear track is in fact not a bear track, the meaning of the panel is still likely to be much the same as just outlined. As already discussed, portions of the symbol are more deeply pecked, and these peck marks are less patinated, than the reminder of the symbol. These differences could indicate either a re-working of an earlier petroglyph, or that this symbol actually consists of only the more deeply pecked portions. That some re-working of the petroglyphs in this panel occurred is indicated by the appearance of the spiral. The innermost half turn of the spiral, from its beginning at the bottom of the symbol (as viewed facing toward the bear track) to its top, is much fainter than the outer portions. This difference results from the fact that the inner half turn is both more lightly pecked and much more heavily patinated than the rest of the spiral. The amount of patination appears to be roughly the same for the deeply pecked portions of the bear track, the right turn symbol, and the outer turns of the spiral; the heavier patination of the inner spiral is similar to that of the rear section of the bear track.

As shown by the photograph reproduced in Figure 33, the deeply pecked portions of the bear track consist of the transverse line with the four forward-projecting perpendicular lines and, behind it, a right turn symbol in which the two straight lines are of about equal length. The former symbol has the meaning broad upward movement (Martineau 1973:152). Thus, these symbols again appear to express the ideas of going up and of turning to the right in connection with going up. And again, the alignment of these two symbols with the direction of the pass suggests that they both refer to the ridge crossing. The translation of the remainder of the panel remains as before.

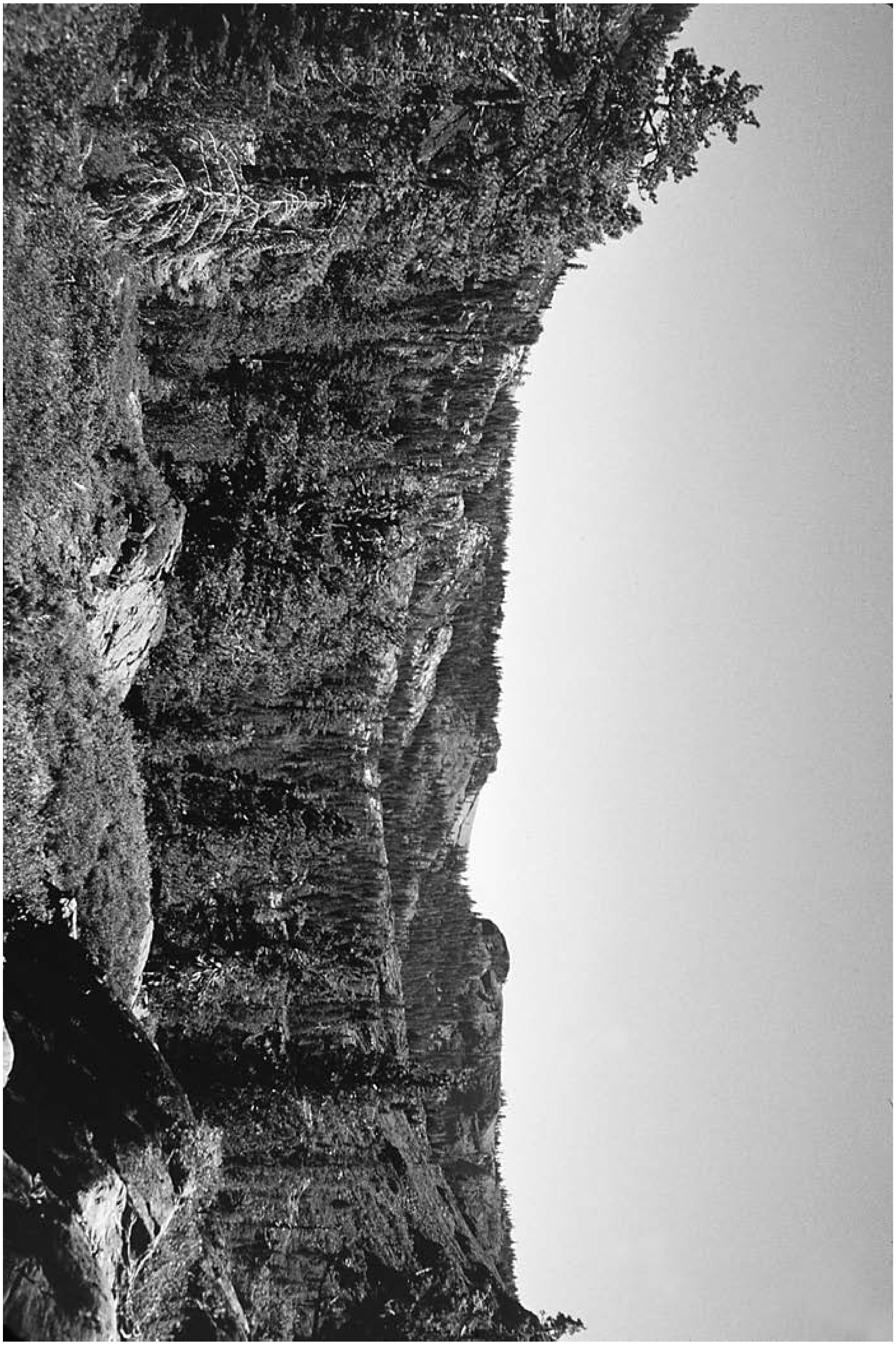

Figure 34. View up Picayune Valley, looking south–southeast. Photograph taken at the point where the present-day trail crosses from the Middle Fork to the Picayune Valley. The pass where the trail leaves Picayune Valley is the low point on the skyline just to the right of center in the figure.

7

Conclusions

If the analysis in the preceding sections is correct, we are led to the following conclusions:

(1) While at first glance certain of the symbols in the petroglyph panel at MFM appear rather crudely drawn and misshapen, these irregularities were in fact deliberate and were intended to convey specific information.

(2) The petroglyph panel at MFM was carefully laid out to match the directions to Departure Peak and the pass over the Picayune Valley ridge line, as well as the angular displacement of the sunrise point along the skyline during the period of one lunation prior to its alignment with Departure Peak.

(3) The authors of the petroglyph panels used at least some of the pictographic symbols and principles of language construction employed by the Indians of the Great Basin region.

(4) The authors of the petroglyph panels knew the length of the synodic period of the moon with an accuracy of at least a quarter of a day.

(5) The date of the summer solstice was accurately known, and some type of day-count calendar was kept.

(6) An event similar in purpose to mid-quarter day in ancient Britain or to mid-season day—the date when the sun is half way (in declination) between the summer solstice and the autumnal equinox—was observed. However, the date of this event was defined as occurring exactly two lunations after the summer solstice, presently August 19–20.

(7) The area where the petroglyphs are located was occupied only seasonally, with the people returning, in the fall, to their winter quarters on the east side of the Sierra crest. The time for their

departure was signalled by the alignment of the sunrise point with Departure Peak, and their exodus was completed on or before October 19–20, so as to avoid the first severe autumn snowstorm. Their departure took place along a trail which went up the Middle Fork to Picayune Valley, then up that valley to a switchback up to a pass over the ridge line, located near the south end of the valley.

(8) The most likely date for the construction of the petroglyph panels at MFM and MFN appears to be between about 400 B.C. and A.D. 01, although some use of the sites may have continued until the eighteenth or nineteenth centuries.

Thus, we see that the ancient Indians of the Middle Fork of the American River not only possessed considerable astronomical knowledge, but also employed sophisticated methods to accurately predict the times of important ceremonies and migrations. To the author's knowledge, this paper provides the first documentation of their astronomical knowledge and capabilities. The findings reported here also deepen our understanding of the petroglyph symbols and the principles of pictographic language construction employed by the Indians of the region, and in so doing lend further credence to LaVan Martineau's ground-breaking studies and interpretations of the petroglyphs of the Great Basin.

Appendix

Weather Observations Near Lake Tahoe

The observed change with time in the average date of the first $\geqslant 4^{d}$ and $\geqslant 10^{d}$ snowfall at Tahoe City could result from a change in the temperature and/or the amount of precipitation at that site. Similarly, the anomalously early snowfall dates observed at Blue Canyon Station No. 3 might result from unusual temperatures and/or precipitation amounts at that location. For a given temperature, an increase in the amount of precipitation will tend to make the first $\geqslant 4^{d}$ and $\geqslant 10^{d}$ snowfall occur earlier, since the increased amount of snow will cause the snow to persist longer on the ground, and conversely. For a given amount of precipitation, a higher temperature will retard, and a lower temperature advance, the date of first $\geqslant 4^{d}$ and $\geqslant 10^{d}$ snowfall.

Thus, in order to investigate the cause of the anomalies in the snowfall dates at Tahoe City and Blue Canyon, the observations of the total monthly precipitation and the average daily maximum, minimum and mean temperatures for the months of September through December were analyzed for the stations listed in Table 3, plus Colfax (elevation 728 m; 2418 ft) and Mount Hamilton (1285 m; 4209 ft). Colfax was added to provide an additional site on the west side of the Sierra Crest, while Mount Hamilton was included as a "control" site, well away from the mass of the Sierra Nevada range. A brief description of the results is given here.

Analysis of the weather observations indicates that no *decrease* in precipitation with time has occurred at any of the stations. Thus, the retardation of the snowfall dates at Tahoe City does not result from this cause. Interestingly, however, certain of the stations have experienced *increases* in precipitation with time. Interpretation of these data is complicated by the fact that significant changes in the locations of the weather instruments were made at all of the stations except Soda Springs and Tahoe City. Consequently, while the complete sets of observations indicate statistically significant (95 percent confidence level) increases in precipitation with time at Blue Canyon (in November), Boca (in September–

November), Colfax (in November), and Truckee (in September–December), these changes could result from systematic differences in precipitation at the different instrument locations at each site. Restricting consideration at all of the stations to the longest interval when the rain gauge was installed at one location at that station, indicated in Table A1, significant increases in precipitation with time are found to occur, during the month of November only, at Blue Canyon, Colfax, Soda Springs and Tahoe City. As shown in Table A1, at each of the stations, November is the first month in the fall when major preciptation occurs. Thus, it appears possible that the November increase in precipitation with time results from "cloud seeding" by the particulate matter in the atmosphere. This "seeding" effect will be greatest at the beginning of the preciptation season in the fall, and will diminish as the particulate material is washed out of the atmosphere by the precipitation. The magnitude of the "seeding" effect will increase with time owing to the ever-increasing concentration of particulate atmospheric pollutants. Support for this hypothesis appears to be provided by the fact that the rate of increase in the November preciptation is greater for the stations west of the Sierra crest than for those east of the crest. West of the crest, the weighted mean rate of the increase for Blue Canyon Stations Nos. 1+2, Blue Canyon Station No. 3, Colfax, and Soda Springs, in November, is

$$\overline{P'}_{\rm w} = +1.411 \pm .046 \text{ mm/y.}$$

On the east side, the weighted mean for Boca, Tahoe City and Truckee is

$$\overline{P'}_{\rm e} = +.273 \pm .190 \text{ mm/y.}$$

The difference, $\overline{P'}_{\rm w} - \overline{P'}_{\rm e}$, is

$$\Delta\overline{P'}_{\rm w\text{–}e} = +1.138 \pm .195 \text{ mm/y.}$$

A difference of this type would be expected with cloud seeding. Typically, the storm systems first encounter the western slope of the Sierras. As a result, cloud seeding will be most effective west of the Sierra crest, and less so along the eastern slope, where the moisture content of the clouds has been depleted by the precipitation that has occurred over the western slope and crest of the range.

While no decrease in precipitation has occurred at Tahoe City, analysis of the temperature data for that site indicates that a very significant *increase* in the average daily temperature—particularly the minimum (nighttime) temperature—has occurred since observations began in 1909. For the period 1909–2004, the mean of the observed rates of change in temperature with time $(\overline{T'})$ for all four months, September–December, weighted by the standard deviations of $\overline{T'}$ for each month are:

$$\overline{T'}_{\rm max} = +.011 \pm .003 \text{ °C/y,}$$
$$\overline{T'}_{\rm min} = +.020 \pm .002 \text{ °C/y and}$$
$$\overline{T'}_{\rm mean} = +.016 \pm .001 \text{ °C/y.}$$

Table A–1. Average Total Precipitation and Daily Maximum and Minimum Temperature.

Station[a] Interval[b]	Month	No. Years[c]		Total Precipitation mm		Average Daily Temperature (°C) Maximum		Minimum		ΔT	
		P	T	P	σ_P	$T_{\max}$	$\sigma_{T_{\max}}$	$T_{\min}$	$\sigma_{T_{\min}}$	$T_{\max}-T_{\min}$	$\sigma_{\Delta T}$
BC	Sep	40	40	20.3	4.3	24.24	.40	+ 7.23	.40	17.02	.57
1+2	Oct	39	39	65.0	8.6	19.53	.38	+ 4.43	.32	15.10	.50
04–43	Nov	39	39	135.9	17.8	14.52	.53	+ 1.31	.27	13.21	.59
	Dec	40	40	226.1	24.6	10.30	.59	– 1.19	.25	11.49	.64
BC3	Sep	51	48	24.8	5.4	22.24	.30	+12.01	.28	10.23	.41
45–104	Oct	51	48	103.4	15.3	17.03	.37	+ 7.79	.32	9.24	.49
	Nov	49	46	240.5	24.2	10.43	.43	+ 2.85	.30	7.58	.52
	Dec	48	45	295.6	34.9	7.51	.45	+ .42	.36	7.09	.58
B	Sep	65	65	15.0	2.3	24.53	.28	– 1.11	.19	25.64	.34
37–104	Oct	65	65	35.1	4.6	18.62	.33	– 4.12	.22	22.74	.40
	Nov	64	64	66.8	7.4	10.85	.33	– 6.98	.24	17.83	.41
	Dec	65	65	90.7	10.2	6.10	.30	–10.38	.42	16.48	.52
C	Sep	68	66	13.0	2.8	28.88	.27	+13.21	.28	15.67	.39
05–75	Oct	69	70	62.7	9.1	23.34	.31	+ 8.68	.24	14.66	.39
	Nov	70	68	135.1	13.0	17.24	.35	+ 4.46	.23	12.78	.42
	Dec	70	71	192.5	16.0	12.79	.33	+ 1.88	.24	10.91	.41
MH	Sep	26	61	24.9	10.7	23.11	.26	+13.63	.31	9.48	.40
29–56(P)	Oct	26	64	32.5	6.1	18.02	.29	+ 9.41	.29	8.61	.41
19–84(T)	Nov	26	62	65.3	12.2	12.83	.34	+ 5.56	.29	7.27	.45
	Dec	27	61	127.0	21.8	9.74	.31	+ 3.03	.27	6.71	.41
SS	Sep	36	36	15.0	2.3	20.37	.31	+ 3.16	.23	17.21	.39
30–69	Oct	36	36	88.9	14.7	14.73	.42	– .61	.19	15.34	.46
	Nov	35	34	165.1	20.3	8.29	.48	– 5.49	.31	13.78	.57
	Dec	35	35	228.6	31.8	4.73	.37	– 9.09	.41	13.82	.55
TC	Sep	94	94	15.2	2.3	21.03	.19	+ 3.56	.14	17.47	.24
09–104	Oct	95	94	43.9	4.6	14.91	.23	– .11	.13	15.02	.26
	Nov	94	94	95.0	8.1	8.36	.20	– 3.28	.15	11.64	.25
	Dec	93	93	131.8	10.7	4.49	.19	– 6.49	.21	10.98	.28
T	Sep	68	68	16.3	2.8	23.64	.29	+ 1.91	.17	21.73	.34
35–104	0ct	69	67	46.5	5.6	17.26	.37	– 1.83	.16	19.09	.40
	Nov	67	66	95.0	9.7	8.97	.34	– 5.68	.22	14.65	.40
	Dec	67	65	136.4	14.0	4.81	.26	– 8.68	.29	13.49	.39

[a] BC = Blue Canyon, B = Boca, C = Colfax, MH = Mt. Hamilton, SS = Soda Springs, TC = Tahoe City, T = Truckee

[b] Intervals are the longest at each station when the locations of the weather instruments remained unchanged, or where no difference in T or P was detectable between locations. The numbers given in the table are the end dates of those intervals, expressed as year minus 1900. At Mount Hamilton, the interval for the precipitation measures is indicated by (P), and that for the temperature measures by (T).

[c] "P" indicates the number of years within the span specified in column one having observations of the total precipitation. "T" indicates the same for observations of temperature; in some cases the number of years for minimum temperature differs by one year.

These values agree closely with those found by Coats et al. (2006) for the entire year:

$$T'_{\text{max}} = +.007°\text{C/y},$$
$$T'_{\text{min}} = +.023°\text{C/y and}$$
$$T'_{\text{mean}} = +.015°\text{C/y}.$$

This increase with time appears to be the cause of the retardation of the dates of the first $\geqslant 4^{\text{d}}$ and $\geqslant 10^{\text{d}}$ snowfall at Tahoe City. A smaller increase has occurred at the other stations studied. Again considering only the longest interval with the thermometers at the same station location (Table A1), the mean of T' ($\overline{T'}$) for all four months at all stations, weighted by the standard deviations for each month and each station, is, for the non-Tahoe stations (including Colfax and Mount Hamilton, and considering Blue Canyon Stations Nos. 1+2 and No. 3 as two separate stations):

$$\overline{T'}_{\text{max}} = +.001 \pm .006\ °\text{C/y},$$
$$\overline{T'}_{\text{min}} = +.012 \pm .006\ °\text{C/y and}$$
$$\overline{T'}_{\text{mean}} = +.007 \pm .002\ °\text{C/y}.$$

The value of $\overline{T'}_{\text{mean}}$ agrees well with current values of the rate of increase of mean temperature due to global warming:

(1) North American Continent (15°–60°N, 50°–140°W), entire year, 1901–2000, $\overline{T'}_{\text{mean}} = +.0075$ °C/y (Jones and Moberg 2003).

(2) Northern hemisphere, land plus sea, entire year, 1901–2000, $\overline{T'}_{\text{mean}} = +.0065$ °C/y (Jones and Moberg 2003).

(3) Northern hemisphere, land plus sea, September–November, 1901–2000, $\overline{T'}_{\text{mean}} = +.0048$ °C/y (Jones and Moberg 2003).

(4) North American Continent (30°–65°N, 40°–165°W), entire year, 1900–1999, $\overline{T'}_{\text{mean}} = +.0069 \pm .0005$ °C/y (Karoly et al. 2003).

Thus, while the non-Tahoe stations show an increase in mean temperature consistent with global warming, the rate of temperature increase at Tahoe City has been significantly larger, and must reflect a change, in addition to global warming, in the microclimate of the Tahoe Basin. Most likely, that change is a result of human activity in the Basin, including the paving of surface areas, the burning of wood and fossil fuels, and the generation of dust and aerosols. It is owing to the much larger rate of increase in temperature at Tahoe City that the resulting retardation of the snowfall dates is detectable only at this location.

At Blue Canyon, Table A1 shows that for each month, the average daily maximum temperature at Station 3 was significantly lower than at Stations 1 and 2, while the minimum temperature was significantly higher. Stations 1 and 2 were located in a canyon, while Station 3 is situated on a ridgetop. Thus, the higher maximum and lower minimum temperatures at Stations 1 and 2 most probably result from the trapping of daytime heat in the canyon and the downslope drainage of cold air (cooled by contact with the cold ground surface) at night. This conclusion is supported by the differences in the ranges of the daily temperatures at the various stations, given in Table A1. The table shows that for each month, the average daily temperature ranges at Blue Canyon Station No. 3 and Mount Hamilton are quite similar, but that these ranges are significantly smaller than those at all of the other stations. Mount Hamilton is situated in the Diablo mountain range, about 80 km from the California coastline, and at night is usually above the top of the temperature inversion which marks the upper limit of the surface convective layer of the atmosphere. Being on the top of the highest peak in the range, the site is also unaffected by nighttime downslope air drainage. Typically such locations have a rather small diurnal temperature variation, with a nearly constant temperature during the night. The similarity between the diurnal temperature ranges at Blue Canyon Station No. 3 and Mount Hamilton therefore suggests that unlike Blue Canyon Stations 1 and 2, and the other Sierran stations, Station 3 is situated in the free air above the convection layer and away from local heating and air drainage effects.

At Blue Canyon, Table 3 shows that the average dates of the first $\geqslant 4^{\mathrm{d}}$ and $\geqslant 10^{\mathrm{d}}$ snowfalls at Station 3 occur in November, and at Stations 1 and 2 in December. In November, as shown in Table A1, the average daily maximum temperature is 4.1 °C lower, while the average daily minimum temperature is only 1.5 °C higher at Station 3 compared to Stations 1 and 2. These differences will cause more of the precipitation to fall as snow, and for the snow to remain longer on the ground at Station 3 than at Stations 1 and 2. Additionally, the average total precipitation in November was 136 mm at Stations 1 and 2 and 240 mm at Station 3, further increasing the amount of snowfall at Station 3. In fact, as shown by Table A1, the total precipitation at Station 3 is appreciably greater than at any of the other Sierran stations in each month from September through December. The precipitation amounts at the other stations west of the Sierra crest (Blue Canyon Stations 1 and 2, Colfax, and Soda Spings) are all fairly similar. For these four months, the average total precipitation at Station 3 is about 1.5 times the average of that at these other west-slope stations.

It is clear, therefore, that both the total precipitation and the diurnal temperature range at Blue Canyon Station No. 3 differ significantly from those at the other Sierra weather stations, and in ways that tend to increase both the amount of snowfall and the persistence of snow on the ground at Station 3, thereby advancing the dates of the first $\geqslant 4^{\mathrm{d}}$ and $\geqslant 10^{\mathrm{d}}$ snowfalls at that location, compared to the other Sierran stations. Consequently, Station 3 was omitted in determining the variation of average snowfall date with elevation, shown in Figure 20.

Notes

[1] Note that much of the glacially polished surface between the areas recorded in the rubbing is missing as can be seen in Figures 4 and 8.

[2] Viewing the sun symbol from the observer's eye position, 147 cm above the bear track, an interesting optical illusion occurs: As a result of its elliptical outline on the rock surface, the symbol appears not only circular but also to be suspended, vertically, floating in the air *above* the flat, horizontal surface on which it is inscribed.

[3] Later renamed "The JPL HORIZONS on-line solar system data and ephemeris computation service." At the time of publication the service was retrievable at http://ssd.jpl.nasa.gov/?horizons.

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