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Petroglyphs, Lightning, and Magnetism

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The passage of a lightning discharge over the surface of a rock is shown to produce two roughly parallel loci of maximum anomalous magnetization, having opposite polarities, marking the edges of the discharge path. For an electron flow from sky to earth, the north-seeking end of a compass needle is attracted to the right-hand locus. Perpendicular to the path, the magnetization varies like that of the field induced in and around a long, straight cylindrical conductor by the flow of an electrical current. Magnetization due to lightning has been observed on the surfaces of rocks in the Providence Mountains of southern California. Petroglyphs on one of these rocks appear to be related to the magnetic anomalies. The present study suggests that a lodestone may have been used to detect and mark certain of these anomalies, rather than observing the actual lightning strikes or their physical traces on the surfaces of the rock.

In the spring of 1988, the writer had the privilege of participating in a research project organized and led by Arlene Benson. The purpose of that project was to discover and map petroglyphs in an area of northeastern California. The petroglyphs in this region are located on the faces of basalt cliffs. In mapping the locations of these petroglyphs, compass readings were made in order to determine the azimuths of the cliff faces on which they were inscribed. These readings were not consistent, showing quite large anomalies in certain locations. Detailed measurements revealed that these anomalies consisted of loci, and that either the north- or the south-seeking end of the compass needle was attracted towards the face of the cliff along the loci. These loci ran more or less vertically from the top to the bottom of the cliff face, and there would often be two of them running more or less parallel to one another a short distance apart, one of which was north- and the other south-attracting.

The appearance of these loci suggested to the writer that these were anomalies induced in the rock by the passage of lightning discharges down the surfaces of the cliffs. Subsequent investigation of the literature revealed that lightning was indeed known to produce remnant magnetism in igneous rocks. The fact that anomalous magnetism could be produced by lightning was first suggested by von Humbolt in 1797 (Merrill et al. 1996:9), and remnant magnetization in basalt due to lightning has been studied by Cox (1961).

Having concluded that the observed magnetic anomalies were due to lightning, it was next investigated whether or not there was any correlation between these anomalies and the petroglyphs inscribed on the same basalt cliffs. No such correlation was found for the petroglyphs in the study area (Benson and Buckskin 1991). Subsequent studies by the writer at other locations have revealed only one instance of a possible association of petroglyphs with lightning strikes. Since other reports of possible relationships of petroglyphs to lightning strikes have been published (Benson and Buckskin 1991; Hoskinson 1990), a description of this case may be of interest.

THE MAGNETIC IMPRINT OF A LIGHTNING STRIKE

Studies of the remnant magnetism induced in rocks by lightning have been published by both Cox (1961) and Graham (1962). These studies have demonstrated the overall characteristics of the magnetic fields induced by lightning strikes, but do not provide detailed descriptions of the small-scale features of the resulting anomalies.

Observations by the writer show that the signature effect of a lightning strike is to produce two lines or loci of maximum anomalous magnetization along the discharge path across the surface of the rock. These lines are more or less parallel, are of opposite magnetic polarity, and—on an inclined or vertical rock face—usually extend from the top to the bottom of that face. The north-seeking end of a compass needle is attracted to the rock surface along one of these lines, while the south-seeking end is attracted along the other.

As indicated above, the remnant magnetization resulting from lightning strikes can be detected by moving a compass along the rock surface, as close to that surface as possible. The best results are obtained using a very small compass (20 mm. or less in diameter).

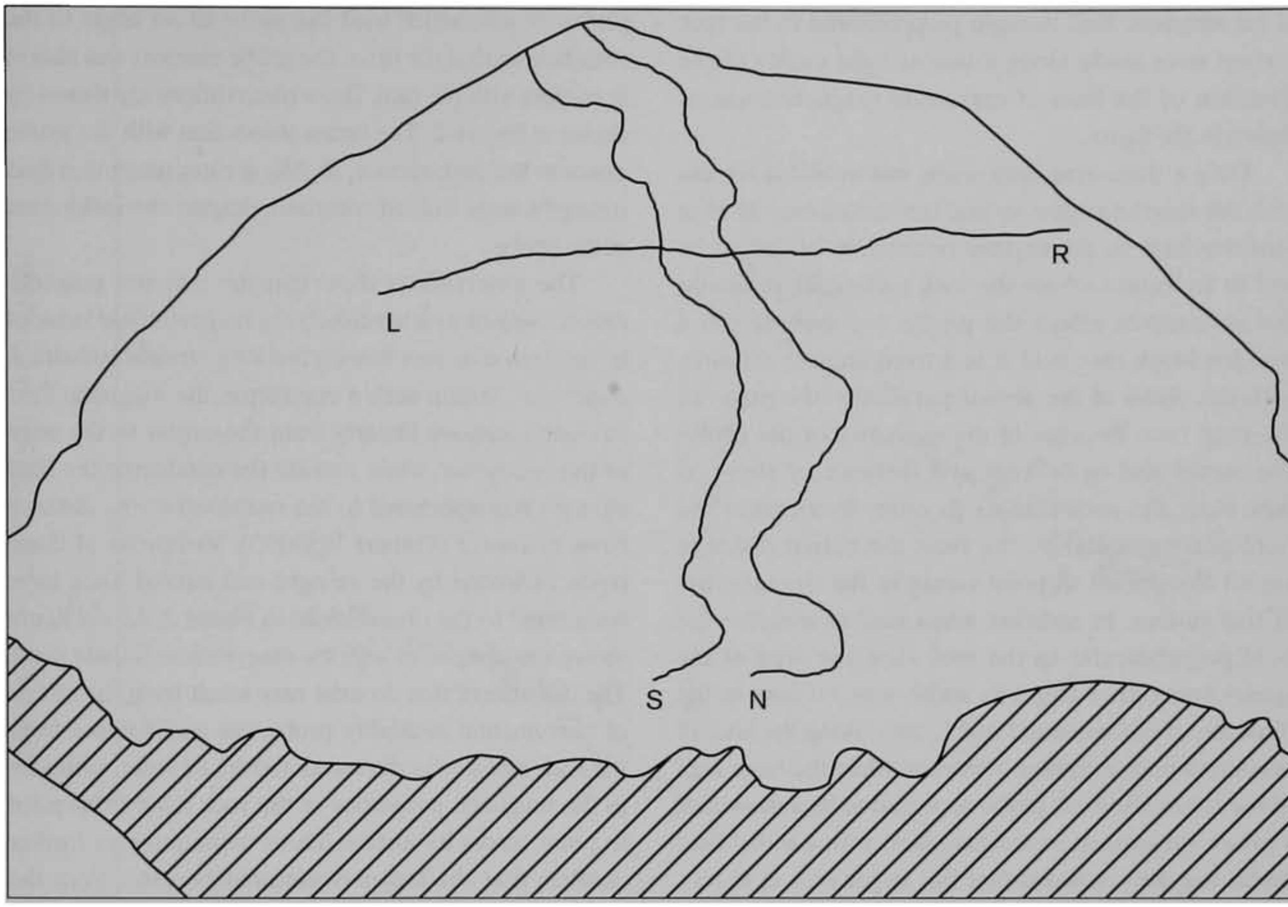

Figure 1. Sketch of south face of pyramidal boulder, showing location of lines of maximum south (S)- and north (N)-attracting remnant magnetization induced by a single, isolated lightning strike. These lines mark the edges of the path of the lightning current, which consisted of a flow of electrons from the top to the bottom of the rock. Magnetometer measurements of the remnant field strength were made along the horizontal line L–R, which extends 40 cm. to the left (L) and 50 cm. to the right (R) of the center of the discharge path; these measures are shown in Figure 2.

The small size makes it possible to bring the center point of the compass closer to the rock face, thereby increasing both its sensitivity to weak fields and its ability to resolve the more closely spaced anomalies. Even so, when using a compass, one will sometimes observe only one locus of a magnetic anomaly, of either north or south polarity, and may entirely miss weak or closely spaced pairs of loci. The detection of only one locus results from the vector addition of the earth's magnetic field to the remnant magnetization, and thus depends upon the orientation of the rock face and the strength of the remnant field, which may be comparable to or weaker than the earth's field. To avoid these problems, a magnetometer should be used in place of a compass whenever possible.

In order to investigate the precise form of the magnetic field induced by lightning, magnetometer observations were made of an isolated lightning strike on a large, pyramidal boulder of volcanic tuff, near site CA-SBr-528 (see below) in the Providence Mountains of southern California. This boulder has a relatively flat southern face, the plane of which has an azimuth of 117° and a northward slope that is approximately 45° above the horizontal. The height of the face is about 1.3 m.; its width at the base of the boulder is approximately 2 m. Two loci of maximum anomalous magnetization about 10 cm. apart run down this north-sloping south face for a distance of about 1 m., from the top of the boulder to near its base, as is shown in Figure 1. The north-seeking end of the compass needle was attracted to the right-hand locus, and the south-seeking end to the left-hand locus; these loci are indicated by lines labeled "N" and "S", respectively, in the figure. Magnetometer measurements of the magnetic field strength perpendicular to the rock surface were made along a line at right angles to the direction of the lines of maximum magnetization, as shown in the figure.

Only a transverse-field probe was available for use with this magnetometer, so that the measurements were sensitive both to the angular orientation of the probe and to its distance from the rock surface. To minimize the orientation effect, the probe was mounted in a wooden block that held it in a fixed angular position, with the plane of the sensor parallel to the plane of the rock face. Because of the geometry of the probe, the sensor had to be kept at a distance of about 15 mm. from the rock surface in order to measure the field perpendicular to the face; the actual distance varied from point to point owing to the irregularities of that surface. In addition, when used to measure the field perpendicular to the rock face, the area of the sensor was rather large; its width was 3.0 mm. in the direction of measurement and 12 mm. along the lines of maximum magnetization. However, while the large area of the transverse-field probe appeared to be a drawback *a priori*, subsequent experimentation with a radial-field probe has demonstrated that this larger area is, in fact, an advantage. The much smaller size of the detector in radial field probes makes measurements with such probes much less satisfactory, since the small detector responds to changes in the magnetic susceptibility of the rock from point to point over its surface, thereby increasing the observational scatter and compromising the detection limits for weak anomalies.

The measurements were also limited in their accuracy by instabilities in both the zero setting and the gain of the magnetometer. Consequently, both the accuracy and spatial resolution of the measured field strengths were lower than could be achieved with better equipment.

The results of several sets of measurements along the scan line are shown in Figure 2. In this figure, the ordinate is the magnetic field strength in gauss, and the abscissa is the distance in centimeters to the right (positive) or left (negative) of the center of the two loci of maximum magnetic field strength. To assess the effect of having the probe 15 mm. from the rock surface, a separate set of measures in the vicinity of the maxima of the remnant magnetism was made using a modified probe mount, which held the probe at an angle to the rock face so that the tip of the probe element was almost in contact with the face. These observations are shown by circles in Figure 2. The figure shows that with the probe closer to the rock surface, slightly greater maximum field strengths were indeed recorded, despite the inclination of the probe.

The observations show that the remnant magnetization resembles rather closely the magnetic field induced by an electric current flowing in a long, straight cylindrical conductor. Within such a conductor, the magnetic field strength increases linearly from the center to the edge of the conductor, while outside the conductor the field strength is proportional to the reciprocal of the distance from its center (Gilbert 1950:175). Variations of these types, indicated by the straight and curved lines, have been fitted to the observations in Figure 2. As the figure shows, the agreement with the observations is quite good. The differences that do exist may result from the effects of instrumental instability, probe size and distance from the rock surface (as discussed above), or from variations in the magnetic properties of the rock itself from point to point across its surface. These measurements further confirm that the magnetic anomalies result from the electrical currents induced by lightning strikes. In addition, they indicate that the lightning discharge occurs as a ribbon of current traveling on or near the surface of the rock and having a width equal to the distance between the two maxima of magnetic intensity.

Note that the direction of the magnetic field induced by a current of electrons flowing downward in a vertical conductor is such that the north-seeking end of a compass needle will be directed away from the observer when the compass is placed on the right-hand side of the conductor, and towards the observer when it is placed on the left-hand side of the conductor. This is the implication of the measurements shown in Figure 2, indicating that the lightning discharge consisted of a flow of electrons down the face of the boulder, from the sky to the earth. This is also the conclusion drawn from all but one of the lightning-induced remnant magnetizations so far observed by the writer, and it is apparently involved in 90% of all lightning strikes (Lewis 1950:418); the one exception is discussed below.

The fact that the midpoint of the pattern in Figure 2 occurs at about 0.45 gauss results from the superposition

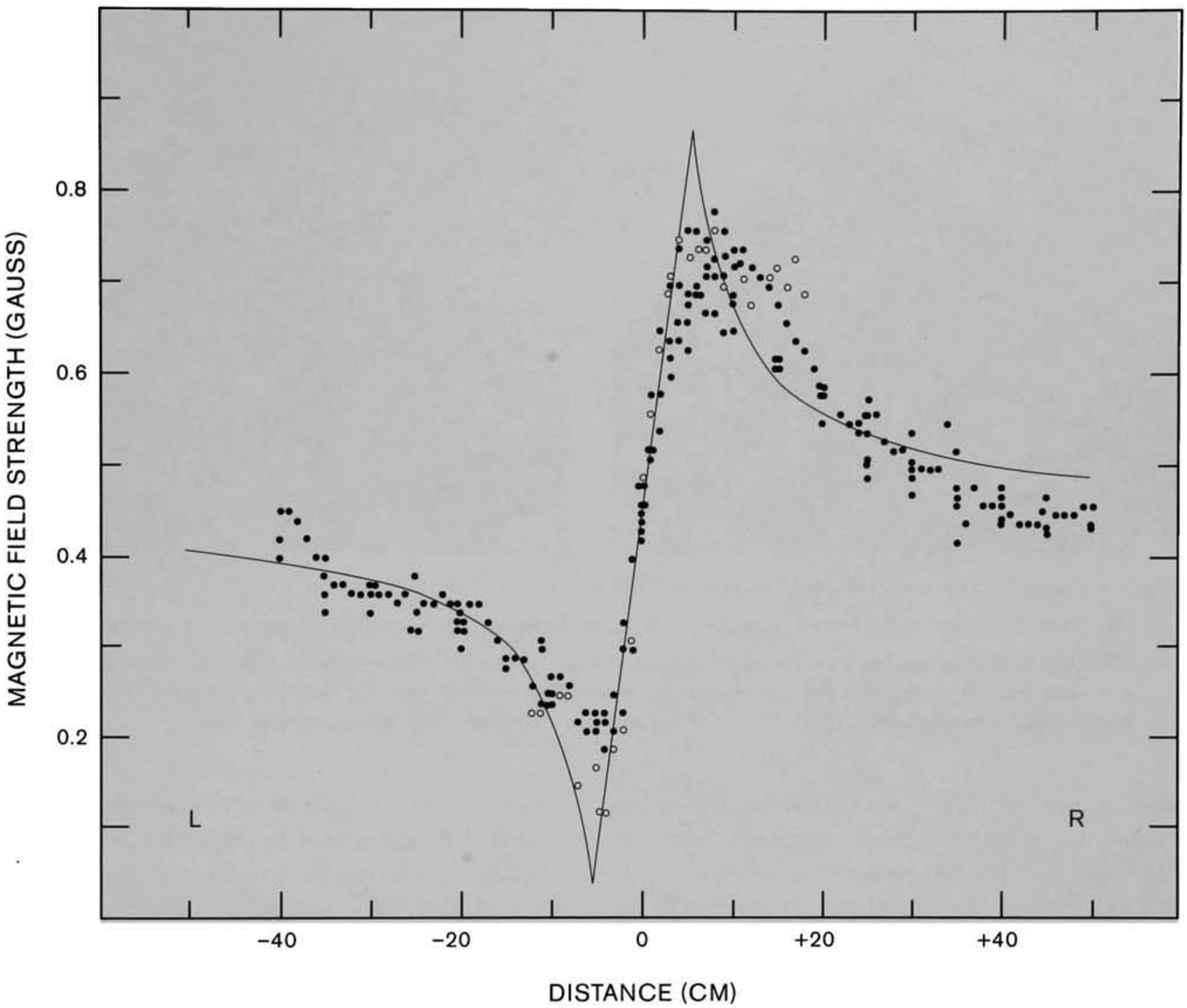

Figure 2. Magnetic field strengths perpendicular to the face of the boulder shown in Figure 1. Ordinate shows magnetic field strength in gauss; abscissa, the position of measurements along the line L–R in Figure 1. Dots show location of observations with transverse probe mounted parallel to the rock face and 15 mm. from the surface. Circles show location of observations with probe mounted at an angle, with tip of probe at the rock surface. Line and curves represent the magnetic field induced within and around a long, straight, vertical conductor, 10 cm. in diameter, by a downward-flowing electron current.

of the component of the earth's magnetic field in the direction of the magnetometer measurements. The total intensity of the earth's magnetic field at the site of these measurements was about 0.50 gauss when the observations were made (Forbes 1987).

That the lightning discharge does occur as a ribbon of current bounded by loci of maximum anomalous magnetic intensity at either edge is confirmed by observations of a second boulder of volcanic tuff in the same vicinity, shown in Figure 3. This boulder consists of a roughly rectangular block of tuff whose northeast face (shown here) is 0.78 m. in width (at the top) and 0.90 m. in height (along its right hand edge). The plane of this surface has an azimuth of 137° and is slightly overhung, being inclined upward towards the northeast at an angle of 70°.

As Figure 3 shows, this face of the rock is traversed by two bands that are slightly lighter than the surrounding surface. That these bands mark the passage of two discharge currents across the rock is

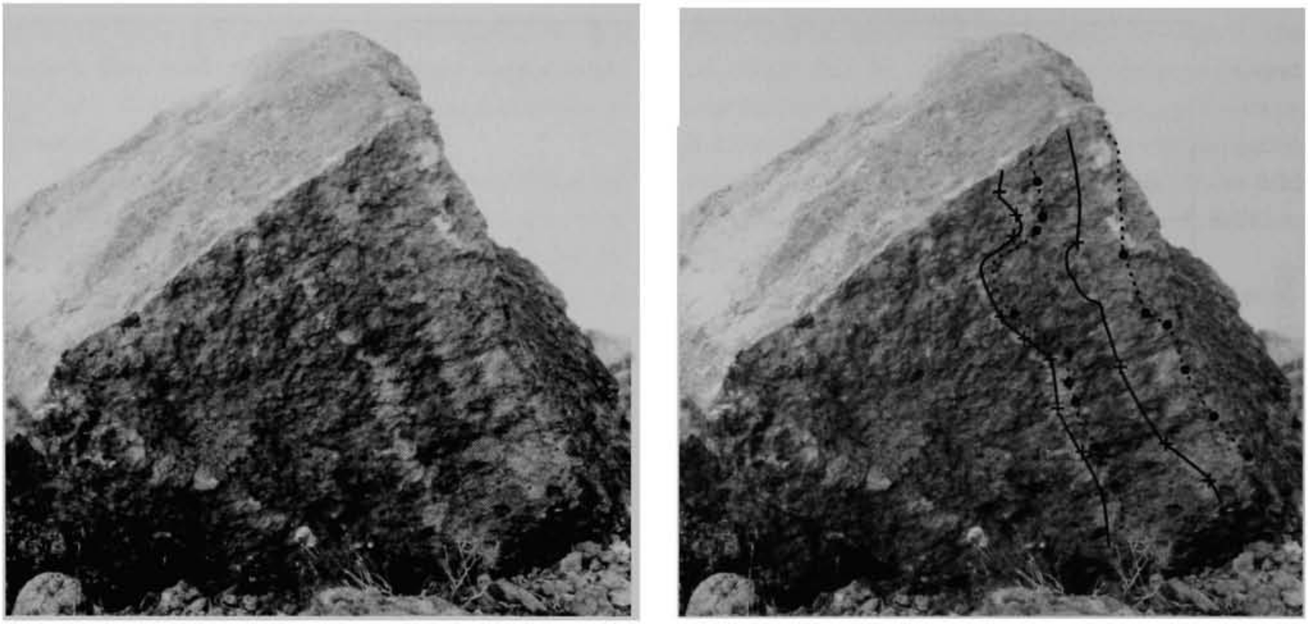

Figure 3. Boulder of volcanic tuff showing surface alteration due to lightning discharges.

(3a). View of northeast face. This face measures 0.78 m. across the top and 0.9 m. from top to bottom along the right-hand side.

(3b). Lightning discharge paths mapped using small (19 mm. diameter) compass. Crosses show observed locations of maximum north-attracting, and dots of maximum south-attracting, magnetic anomaly. Solid lines indicate loci of maximum north-attracting magnetization. Dashed lines indicate loci of maximum south-attracting magnetization.

demonstrated by the fact that each is bounded by loci of maximum magnetic anomaly, as shown in Figure 3b. These loci were mapped using a small compass 19 mm. in diameter. The locations of the observations of the maximum north-attracting magnetic anomalies observed with the compass are indicated by crosses, and of the maximum south-attracting magnetic anomalies by dots. Note that in this instance—which is the sole example among the discharge paths so far investigated by the author—the direction of the electron flow is reversed, being from ground to sky, so that the north-seeking end of the compass is attracted to the left-hand sides of the paths. Since both paths show this unusual flow direction, it appears likely that both originated from the same lightning strike. The two paths appear to coalesce at or near the upper right-hand corner of the face, where they then disappear. The discoloration of the discharge paths is rather slight, but it appears to be uniform across the widths of the paths, which measure 3 cm. (left) and 9 cm. (right) across. Preliminary magnetometer measurements indicate that the field strength difference across the paths is $\Delta F = 0.4$ gauss (left) and 0.9 gauss (right); this strength was sufficient to cause the north-seeking pole of the (19 mm.) compass to point directly towards the rock face along the left-hand sides of the discharge paths.

This is the only instance so far observed by the writer where an alteration in the appearance of the rock surface due to the passage of a lightning discharge current over it can be detected, suggesting that such effects, if and when they occur, may be rather short lived, and are soon obliterated by the effects of the weather. In the present case, the northeast face of the rock is (as indicated above) somewhat protected from the weather by its 20° overhang, which is perhaps enough to have preserved at least a trace of the surface alteration. However, this strike may simply be of fairly recent origin, so that (with some protection) the surface discoloration has not yet had time to be erased.

Note that the light-colored streak at the left-hand edge of the face does not have associated anomalous magnetization. In addition, this streak—unlike the other two—is of uneven visibility along its length. It thus appears not to be due to a lightning discharge, but rather to the surface deposition of minerals (possibly Corrensite) washed down from the top of the rock or leached out from its interior.

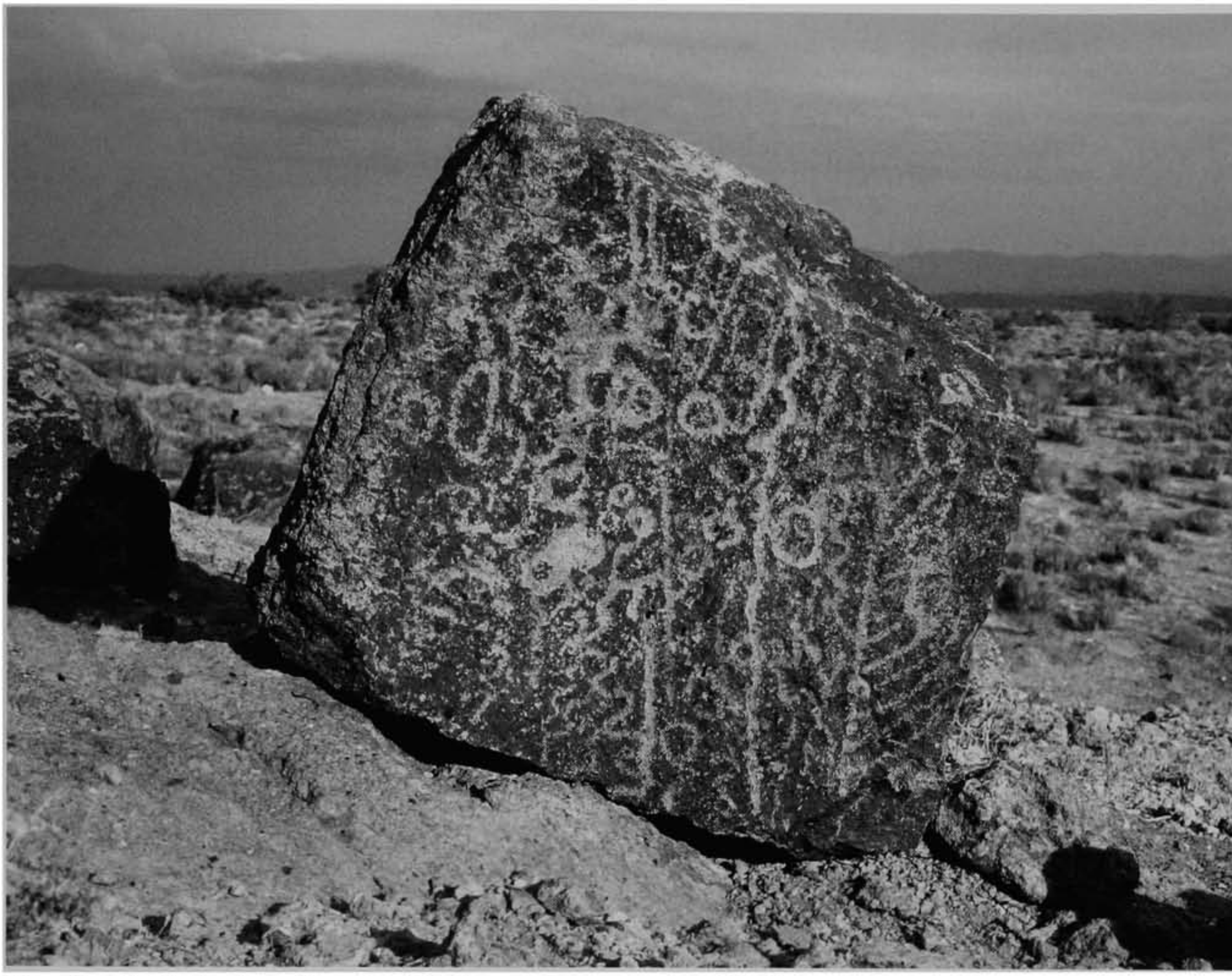

Figure 4. Lightning Rock, northwest face. This face is 1.14 m. across and 1.07 m. from top to bottom.

OBSERVATIONS OF LIGHTNING ROCK

Site CA-SBr-528 is located in the Providence Mountains of southern California, in an area containing numerous rocks, boulders, and cliffs of volcanic tuff. The site itself is situated in a large complex of boulders, and contains a number of medium to very large-sized boulders with petroglyph panels, some of which are quite large and complex. Several of the boulders at this site display magnetic anomalies due to lightning discharges, and one boulder has both magnetic anomalies and petroglyphs. However, there is no evidence of any relationship between them; their occurrence on the same rock surface appears to be solely due to chance.

To the west of the complex containing SBr-528 is a field of scattered rocks and boulders of volcanic tuff which extends about 42 m. north–south and 118 m. east-west. These rocks range from a few centimeters to about 4.5 meters in size (at the western edge of the SBr-528 complex). Those rocks in this field having heights and/or widths greater than 0.5 m. were surveyed for petroglyphs and magnetic anomalies. (The smaller rocks were omitted owing to the likelihood that any such rocks that had once contained petroglyphs would by now have been removed.) Out of the 36 rocks surveyed, only four (including the two discussed above) displayed anomalous magnetization due to lightning discharges, and only two of the 36 had petroglyphs. Only one had both magnetic anomalies and petroglyphs; it is on the surface of this one rock, out of all the rock surfaces so far studied, that there appears to be a correlation between at least some of the petroglyphs and the anomalous magnetization.

The rock in question, referred to hereafter as "Lightning Rock," is shown in Figures 4 and 5. It is

Figure 5. Lightning Rock, top looking east-southeast. Width of top is 0.73 m. northwest to southeast.

located in the boulder field, about 46 m. west of SBr-528, and is a roughly rectangular block of volcanic tuff. Its northwest face measures 1.07 m. in width by 0.88 m. in height; it is nearly vertical. Its plane lies in azimuth 39°. The top surface measures 1.07 m. northeast to southwest and 0.73 m. northwest to southeast, and it slopes upward at an angle of about 39°, with the uppermost point being its east corner. The northwest face, shown in Figure 4, is inscribed with numerous petroglyphs that cover nearly the whole surface. The top, shown in Figure 5, has only a few petroglyphs: four parallel lines extending southeastwards from the northwest edge, a circle near the west corner, a line extending northeastwards from the southwest edge, and a bent line near the west corner. The northeasternmost of the four parallel lines extends across the entire width of the top, while the next two extend only half way, and the fourth (southwesternmost) extends only about one quarter of the way across the top. No petroglyphs are found on the northeast and southeast sides. However, under the most favorable lighting (late afternoon winter sun), a single extremely faint, heavily patinated petroglyph can be detected on the southwest face, as shown in Figure 6. The left-hand photograph (Fig. 6a) was taken one hour before sunset nine days before the winter solstice, while the right-hand (Fig. 6b) was taken in the afternoon in mid-April and represents a more typical illumination of the rock surface. The petroglyph is faintly visible in Figure 6a, but is essentially invisible in Figure 6b.

The initial detection and observation of the magnetic anomalies present on Lightning Rock was carried out using a Keuffel and Esser "Recon" compass, having a total needle length of 62 mm. and outside dimensions of 9 x 10 cm. The results of these initial observations are shown in Figure 7. Here, individual points where the north- or south-seeking end of the compass needle was most strongly attracted to the rock surface are indicated by crosses and dots, respectively. As the figure shows, a number of magnetic anomalies were detected on the northwest face, and a few were found on the top. None were detected on the other three sides. On the northwest face, these anomalies formed vertical lines of north-and/or south-attracting magnetization that clearly resulted from lightning discharges across that face. Since the northwest face and top are the same surfaces where the clearly visible and only slightly-patinated petroglyphs are located, these observations suggested the possibility of a connection between the petroglyphs and the lightning

Figure 6. Lightning Rock, southwest face. This face measures 0.73 m. across and 1.14 m. from top to bottom.

(6a). Face illuminated by sun one hour before sunset nine days before the winter solstice.

(6b). Face illuminated by afternoon sun in mid April.

discharges. The existence of such a connection was further supported by four additional facts:

(1) Lightning Rock is the only isolated rock in the boulder field west of SBr-528 having both a large number of petroglyphs and/or more than one or two lightning discharge paths. Only two of the boulder-field rocks have petroglyphs, and the one other rock with petroglyphs has only a set of nine circles. The three other rocks that do display one, or in one case two, lightning discharge paths have no petroglyphs.

(2) The general appearance of the petroglyph panels on the top and northwest face of Lightning Rock is noticeably different from that of the nearby panels at SBr-528. Two of the larger panels at this site are illustrated in Figure 8. Comparison of Figures 4, 5, and 8 shows that while the style and technique of inscribing the petroglyphs appear similar, the panels at SBr-528 lack the long, strong straight lines that are prominent features of the panels on Lightning Rock.

(3) All of the larger petroglyph panels at SBr-528 are located in such a manner that the creators and viewers of these panels were shielded from the pervasive winds. In contrast, the petroglyphs on the top and northwest face of Lightning Rock are fully exposed to the wind, suggesting that they *had* to be placed there; a more comfortable location could not be used.

(4) The top and northwest face, bearing all of the more recent, readily visible petroglyphs, are pointed away from the direction from which Lightning Rock would most likely have been viewed by a contemporary traveler passing through the region. Thus, the location of these petroglyphs was not chosen to make them readily noticeable. Instead, they again appear to

Figure 7. Lightning Rock. First observations of remnant magnetic fields, using large Keuffel and Esser compass. Dots indicate points where south-seeking end of compass was most strongly attracted to the rock. Crosses indicate where the north-seeking end was most strongly attracted. Lines joining dots indicate broad regions of attraction of the south-seeking end of the compass.

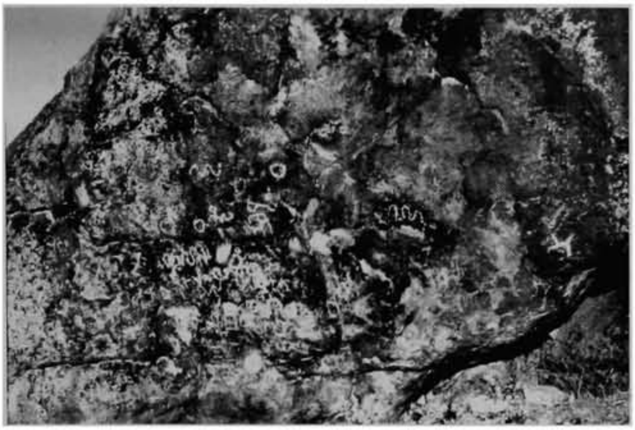

Figure 8. Petroglyph panels at CA–SBr–528, on boulders of volcanic tuff. The photographs cover widths on the rock faces of 3.8 m. and 2.2 m. in Figures 8a and 8b, respectively.

have been placed where they *had* to be placed; i.e., where the lightning discharge paths occur.

In view of these findings, a more detailed mapping of the magnetic anomalies was carried out, using the magnetometer described above. The results of this survey are shown in Figures 9 and 10. Here, loci of maximum north-attracting magnetization are indicated by solid lines, and maximum south-attracting magnetization by dashed lines. Since the solid lines mark the right-hand boundaries of the discharge paths, all of the lightning discharges on Lightning Rock consisted of electron flows from the sky to the earth, as was the case with the discharge illustrated in Figures 1 and 2.

Figure 9 shows that the northwest face of Lightning Rock bears the magnetic traces of at least five different lightning discharges. Number 1, the northernmost of the discharge paths, is rather narrow, having a width of only about 35 mm. Owing to the small separation of the loci of north- and south-attracting magnetization, this discharge path was not detected using the compass. The next discharge path to the south, number 2, divides into two paths, numbered 2 and 2A, to the right of path 2, about half way down the face of the rock. The third path extends from the top to the bottom of the rock face, but—on the lower half of the face—is partly overlain by path number 4. Finally, discharge path number 5 envelopes the south corner of the rock. The south-attracting locus of this path lies along the extreme right-hand edge of the northwest face, while the north-attracting locus lies just around the corner of the rock, on the southwest face, as can be seen in Figure 10.

Figure 10 shows that in addition to path 5, the southwest face has a single discharge path, number 6, which descends the middle of this face. Another single discharge path, number 7, also descends the northeastern part of the southeast face. This face is not shown in the figures, but the beginning of the path can be seen in Figure 10.

All of these discharge paths originate on the top surface of the rock, as shown in Figure 10. As Figures 9 and 10 show, discharge paths 1 and 2 originate from a single initial lightning strike, which impacted Lightning Rock on its highest point, near the east corner of its top surface. Discharge paths 3, 4, 5, 6, and 7 appear to have originated from a second initial strike near the center of the top.

Overall, the agreement between the magnetometer and the initial compass observations is reasonably good. The differences that do exist appear to result, for the most part, from the lower resolution of the compass. One significant difference does occur in the polarities of the compass observations that lie along the lower half of the north-attracting locus of path 2A. These points were detected by the compass as being south-attracting. However, the compass deviations at these locations are rather small, amounting to only about 20°, and appear to result from the combined fields of the nearby discharge paths. This difference illustrates the difficulty in using a large compass to map lightning-induced magnetization.

Using the magnetometer, the magnetic field strength was measured along two lines across the northwest face. The locations of these lines are shown in Figure 11,

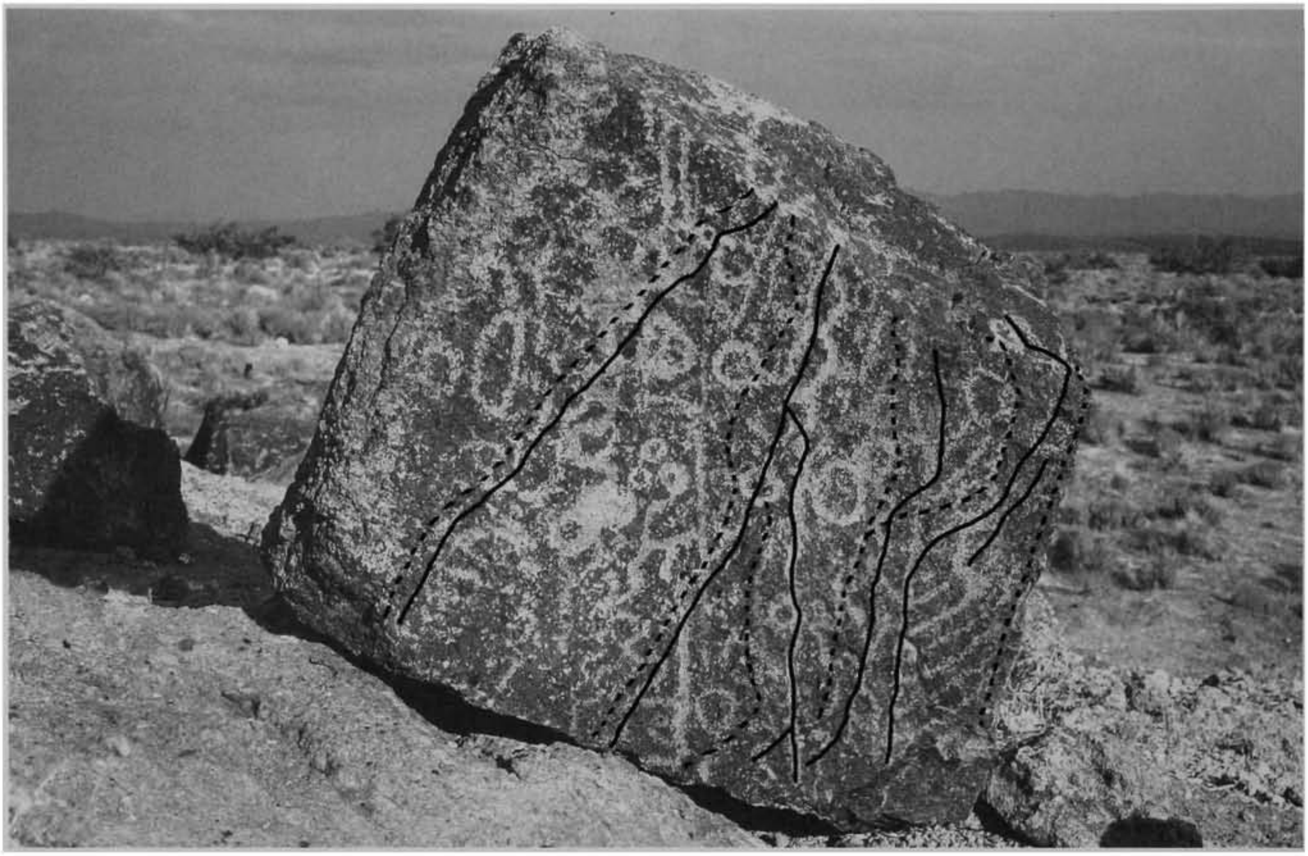

Figure 9. Lightning Rock. Lightning discharge paths on the northwest face mapped using a magnetometer (see text). Dashed lines indicate loci of maximum south-attracting magnetization. Solid lines indicate loci of maximum north-attracting magnetization. These lines mark the edges of the discharge paths. The discharges consisted of electron currents flowing from top to bottom of the face.

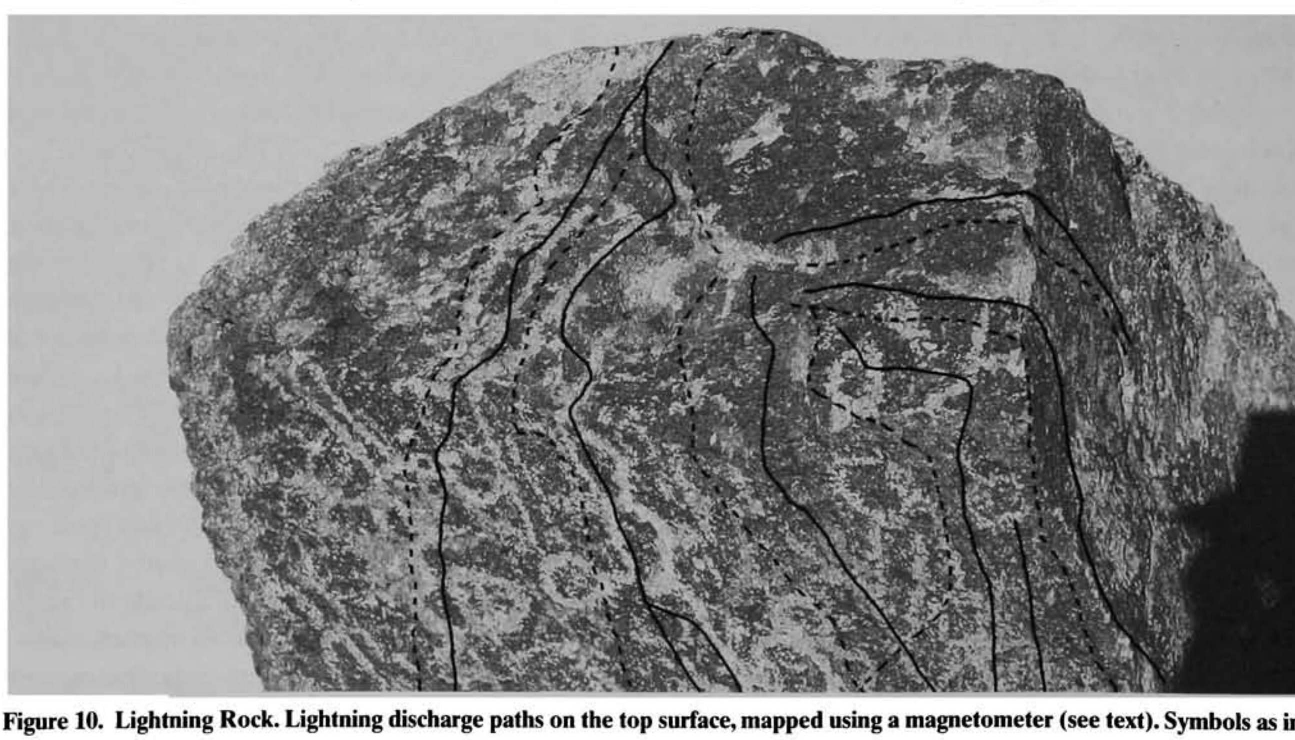

Figure 10. Lightning Rock. Lightning discharge paths on the top surface, mapped using a magnetometer (see text). Symbols as in Figure 9.

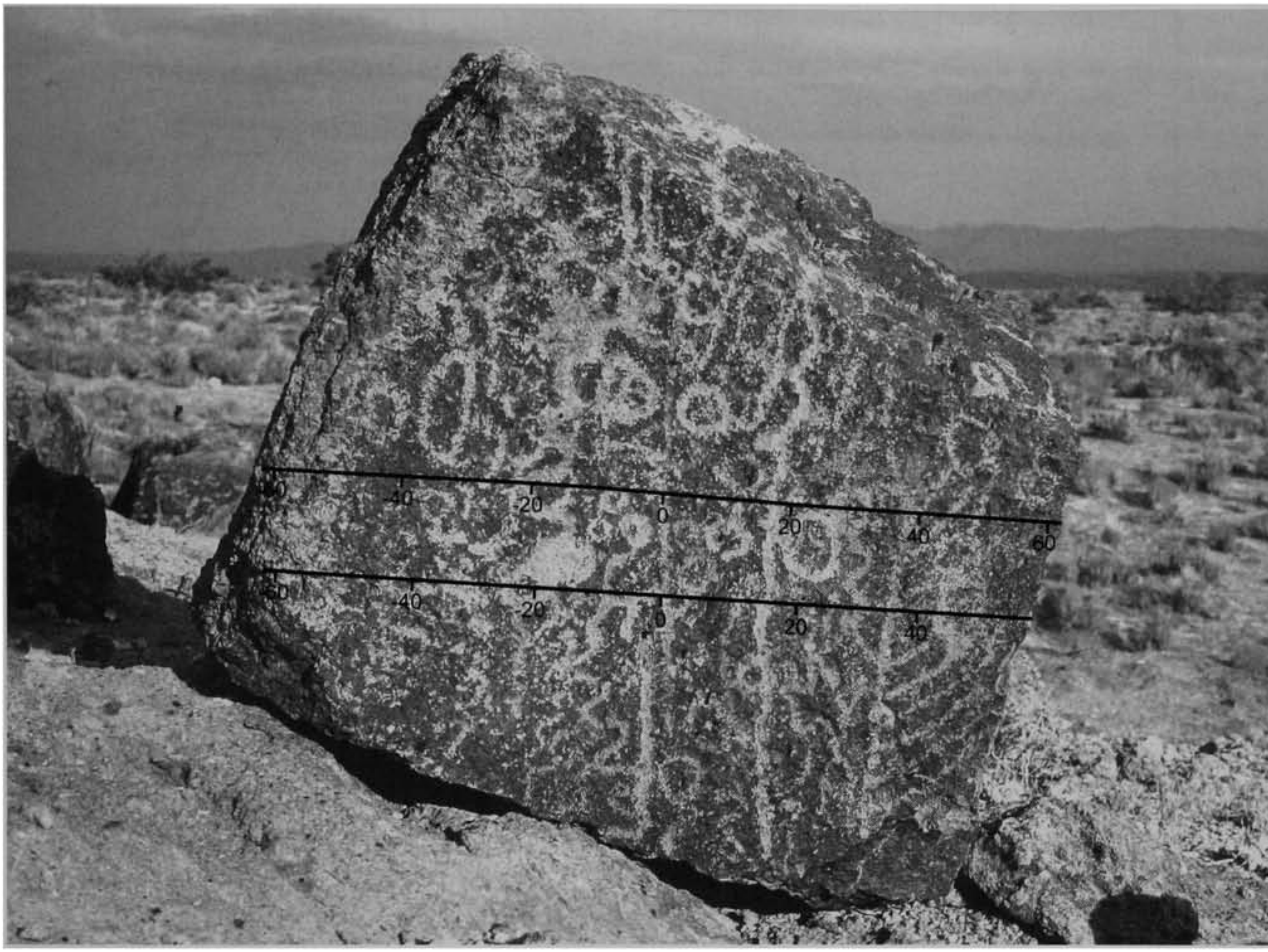

Figure 11. Lightning Rock. Northwest face, showing locations of the magnetometer measurements of magnetic field strength plotted in Figure 12. Numbers indicate position (*D*) in cm. along the upper and lower location lines.

and the observed magnetic field strengths are plotted in Figure 12. The widths and field strengths of the discharge paths at the positions of these two lines are listed in Table 1. This table gives the positions of the maxima of the remnant magnetization along the lines in Figure 11, and the difference, ΔF, in the field strength between the maxima of the south- and north-attracting magnetization for each path. The magnetic field strengths of the paths are then $\Delta F/2$. These fields range from about 0.02–0.26 gauss, while the widths of the discharge paths range from 3–13 cm.

Figures 9 and 10 show that there is a close correlation between the positions of some of the loci of maximum field strength and certain of the petroglyphs. On the northwest face, all or parts of the north-attracting loci of paths 2, 2A, 3, and 4 coincide almost exactly with vertical petroglyph lines. On the top of the rock, the south-attracting locus of path 1 and the north-attracting locus of path 2 both lie on or close to the northern- and southernmost of the three longer parallel petroglyph lines located near the northern end of the rock. The north-attracting locus of path 1 lies just to the left of the middle petroglyph line, while the south-attracting locus of path 2 lies just to the right of this line. Near the northwest edge of the top, the north-attracting locus of path 2 bends southward and then lies along the fourth (and shortest) parallel petroglyph line for about half of its length before descending the northwest face. These coincidences suggest even more strongly than the initial compass observations that at least these particular petroglyph lines are in some way related to the lightning discharges.

If the petroglyph lines, or some of them, are indeed related to the lightning strikes, what was it that the native observers saw and recorded? The lightning strikes might have been detected in two different ways: (1)

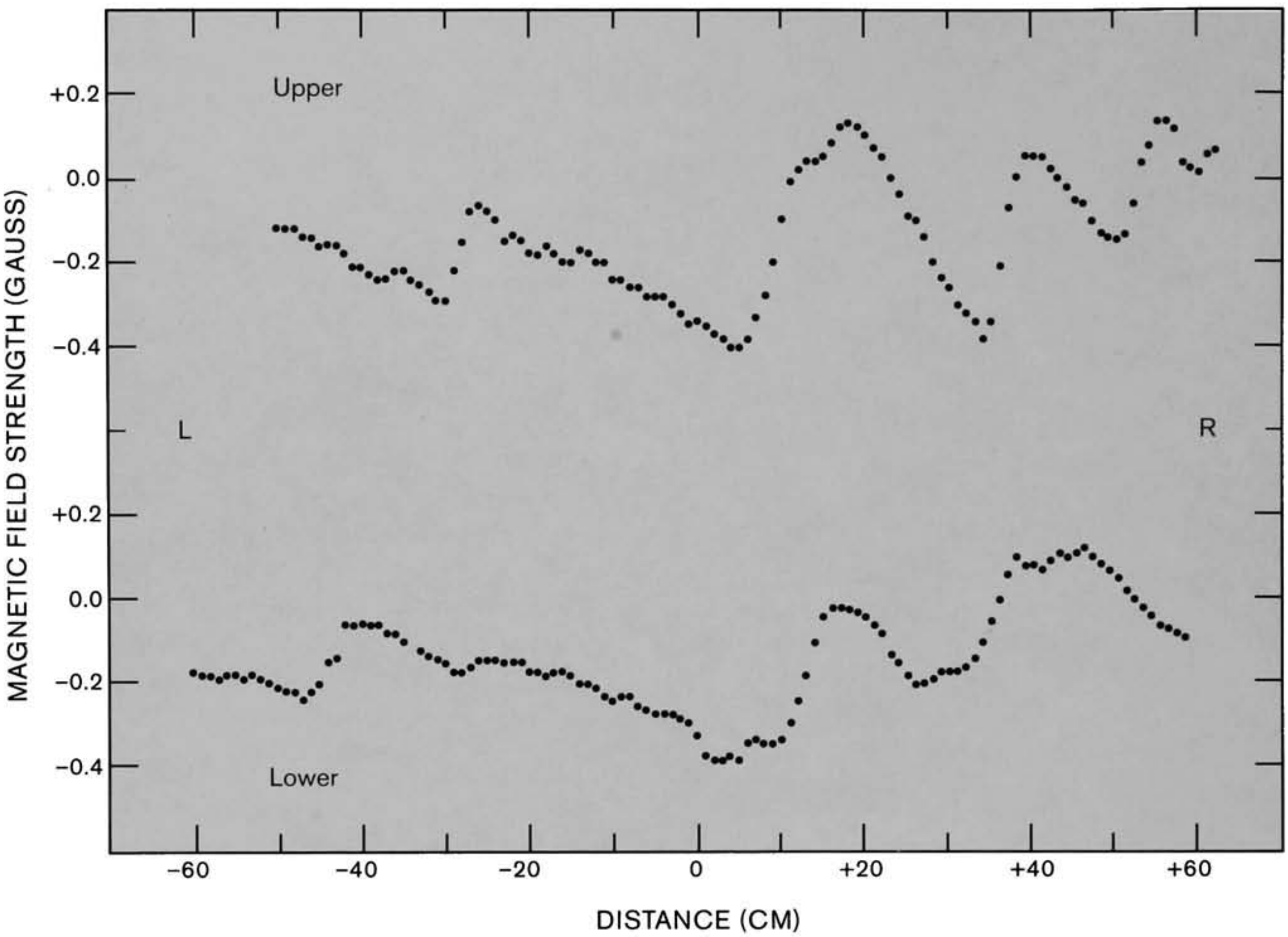

Figure 12. Magnetometer measurements on the northwest face of Lightning Rock, along the location lines shown in Figure 11. Ordinate shows magnetic field strength, in gauss, perpendicular to the rock face. Abscissa shows position (*D*) in cm. along the upper and lower location lines in Figure 11.

the lightning might have been observed to strike the rock and to produce some temporary discoloration or alteration of the surface; or (2) the unusual magnetic properties of the rock might have been detected and locations with anomalous magnetization recorded.

Based on the observations discussed above, it is evident that if the lightning discharges on Lightning Rock produced visible alterations of the rock surfaces, these altered regions would have consisted of bands extending across the top and down the sides of the rock, with the widths of these bands being equal to the distances between the loci of maximum south- and north-attracting magnetic field strength associated with the different discharges. We might expect, then, that the observer would do one of three things: (1) mark the entire width of the discharge band on the surface of the rock; (2) mark the two edges of the band; or (3) inscribe a single line down the middle of the band. This is not what we find.

On the northwest face, we see that only portions of two of the discharge paths match petroglyph lines, and in these instances only the loci of maximum north-attracting magnetic field lie along or close to these lines. On the top, the outer edges of paths 1 and 2 do match the northern- and southernmost of the three longer parallel petroglyph lines. However, their inner edges are not marked by petroglyph lines. Instead, the middle of the three longer parallel lines lies midway between these edges. The three petroglyph lines possibly were intended to outline paths 1 and 2, represented as having no space between them. However, as Figure 10 shows, there are five other discharge paths on the top surface of Lightning Rock. The magnetometer measurements indicate that the field

Table 1

LIGHTNING ROCK: FIELD STRENGTH OF MAGNETIC ANOMALIES ON THE NORTHWEST FACE

Traverse[a]	Path No.	Maximum Field Strength Position[a] and Discharge Path Width[b] (CM.) D_S[d]	D_N[e]	W[f]	Change in Field Strength Across Path[c] (GAUSS) ΔF
UPPER					
	1[g]	-30.5	-26	4.5	0.23
	2	+ 5	+13	8	0.44
	2A	+ 5	+18	13	0.53
	3	+34	+40	6	0.43
	4	+49.5	+55.5	6.0	0.28
LOWER					
	1	-47	-41	6	0.18
	2	+ 2.5	+ 7	4.5	0.05
	2A	+ 8.5	+17	8.5	0.32
	3	+26.5	+29.5	3	0.03
	4	+26.5	+38	11.5	0.30

[a]See Figure 10

[b]See Figure 11

[c]Difference in field strength between the south- and north-attracting magnetic maxima at D_s and D_n, respectively

[d]Position of maximum south-attracting field

[e]Position of maximum north-attracting field

[f]Width of discharge path (D_n - D_s)

[g]Measurements perpendicular to this path at a point 44 mm. below the upper traverse line give W = 35 mm. and ΔF = 0.16 ga uss

Table 2

LIGHTNING ROCK: LODESTONE OBSERVATIONS ALONG THE NORTHWEST FACE

Lodestone Location[a]	Azimuth of Lodestone North[b] (DEG)	Notes
1	354	No deviation
2	354	No deviation
3	354	No deviation
4	309	Lodestone axis approximately perpendicular to rock face. South-seeking end of lodestone points to south-attracting locus of discharge path 2A
5	264	Location is just below small compass location No. 4 (Figure 13). South-seeking end of lodestone points slightly north of perpendicular to rock face
6	90	Location is just below small compass location No. 6 (Figure 13). North-seeking end of lodestone points to petroglyph line just to north; i.e., north-attracting locus of discharge path 2A
7	16:	Slight eastward deviation of north-seeking end of lodestone; south-seeking end points to south-attracting locus of discharge paths 3 and 4, just to the south (":" indicates greater uncertainty)
8	309	Axis of lodestone perpendicular to rock face
9	90:	North-seeking end of lodestone points to petroglyph line to north; i.e., north-attracting locus of discharge path 4 (":" indicates greater uncertainty)
10	354	No deviation

[a]Numbers refer to locations shown in Figure 12

[b]Azimuth of magnetic north at the northwest face of Lightning Rock, away from effects of the lightning discharges, is 354° (see text). Azimuths given are approximate, being estimated from photographs of the suspended lodestone at the indicated locations

strengths of these discharge paths are the same as or greater than those of paths 1 and 2. Yet only one of these, a portion of the north-attracting locus of path 6, is marked with a petroglyph. These results suggest that the native observers were not recording the actual lightning strikes or their immediate after-effects on the appearance of the rock surfaces, but were, instead, detecting and marking the remnant magnetism produced by these strikes.

Could the native observers have, in fact, detected these magnetic anomalies? If they did so, they would most probably have used a piece of naturally magnetized magnetite or "lodestone," either suspended by a fiber or floated on a piece of wood in a container of water, as their detector. An experiment was therefore carried out to determine to what extent the anomalous magnetization shown in Figures 9 and 10 can be detected with such a device.

For this experiment, a piece of magnetite was shaped into a roughly rectangular block approximately 55 mm. in length, 40 mm. in width, and 12 mm. in thickness. The block was then magnetized along its 55-mm. axis to a field strength of about 50 gauss. (This value was chosen because naturally occurring fields of that strength were observed in specimens of magnetite at a mineral deposit in the Providence Mountains in the same general region as SBr-528.) Observations were then made at 10 points along the northwest face of Lightning Rock that involved photographing the lodestone, suspended by a thread about 50 cm. in length, at these positions. The locations of these points are indicated in Figure 13, and the observed azimuth of the north-seeking end of the lodestone at each point is listed in Table 2. These azimuths are only approximate, being estimated from the photographs. Details of the observations are given in the notes to Table 2.

Figure 13. Lightning Rock, northwest face. Numbered dots indicate the locations of the lodestone observations listed in Table 2.

The observations show that it is indeed possible to detect some, but not all, of the magnetic anomalies using a lodestone. As with the original compass observations, discharge paths 1 and 2 were not detected. As discussed above, this is probably due to the narrowness of these paths, so that as seen by the compass or lodestone, the effects of the north- and south-attracting maxima tend to cancel each other. The south-attracting maxima of paths 2A and 3 plus 4 are detected, but owing to the azimuth of the rock face, produce only moderate deviations of the lodestone's axis. *Spectacular* deviations are produced by the north-attracting maxima of paths 2A and 4, where the axis of the lodestone completely reverses direction, so that its north-seeking end points to the location of the north-attracting maxima on the rock face.

The lodestone observations were difficult to make because of the persistent wind at the site. Therefore, in order to obtain a more precise and detailed picture of what it might have been possible for Native Americans to observe using a lodestone detector, additional measures along the northwest and southwest faces and on the top of Lightning Rock were made using a small compass 19 mm. in diameter.

For the northwest face, this compass was mounted on a non-magnetic tripod and moved along the face of the rock. Observations were recorded at 18 locations by photographing the compass and adjacent rock face. The locations of these observations are indicated in Figure 14. The measurements are listed in Table 3, which gives the azimuth of compass north for each position. Note that

Table 3

LIGHTNING ROCK: COMPASS OBSERVATIONS ALONG THE NORTHWEST FACE[a]

Lodestone Location[b]	Azimuth of Compass North[c] (DEG)	Notes
1	354	No deviation
1	354	No deviation
2	354	No deviation
3	331	Compass south points to south-attracting locus of path 2A
4	264	Compass south points to south-attracting locus of path 2A
5	151	Compass north points to middle of petroglyph line coinciding with north-attracting locus of path 2A
6	90	Compass north points to middle of petroglyph line coinciding with north-attracting locus of path 2A
7	61	Compass north points to middle of petroglyph line coinciding with north-attracting locus of path 2A
8	354	No deviation
9	354	No deviation
10	331	Small deviation, compass south slightly attracted to south-attracting locus of paths 3 and 4
11	84	Compass north points to middle of petroglyph line coinciding with north-attracting locus of path 4
12	72	Compass north points to middle of petroglyph line coinciding with north-attracting locus of path 4
13	61	Compass north points to middle of petroglyph line coinciding with north-attracting locus of path 4
14	16	Compass south points to south-attracting locus of path 5
15	354	No deviation
16	129	Compass north points to middle of north-attracting locus of path 2
17	309	Compass south points to south-attracting locus of path 3
18	129	Compass north points to petroglyph line coinciding with north-attracting locus of path 3

[a]Using small compass with center of rotation approximately 10 mm. from rock face

[b]Numbers refer to locations shown in Figure 13

[c]Azimuth of compass north at the northwest face, away from the effects of the lightning discharges, is 354° (see text)

close to the northwest face, at points well away from the lightning discharge paths, the azimuth of compass north is 354°, whereas the azimuth of magnetic north is 12° (Forbes 1987). This 18° difference results from the slight overall south-attracting magnetization of the northwest face of Lightning Rock, shown by the average field strength of the measures in Figure 12. Details of the observations are given in the notes to Table 3. As was the case with the lodestone, the south-attracting maxima of paths 2A, 3, and 4 are detected, but produce only moderate deviations of the compass owing to the azimuth of the rock face. Large deviations occur for the north-attracting maxima of paths 2A and 4, and for the upper portion of path 2, where the path width is large enough so that the effects of the south- and north-attracting maxima do not cancel each other. The small compass was also used to reexamine those points along the lower half of the north-attracting locus of path 2A, where the initial large compass observations indicated maximum south-attracting polarity. At these points, the small compass indicated maximum north-attracting magnetization, in agreement with the magnetometer measurements. This result again illustrates the superiority of a small compass in mapping lightning-induced magnetization.

The top of Lightning Rock was scanned for magnetic anomalies by moving the compass back and forth across its surface. It was found that compass deviations occur mainly near the four parallel petroglyph lines near the north corner of the rock. To record these deviations, the compass was placed on the rock and leveled. Initially, the compass and surrounding features of the rock surface were then photographed. Subsequently, additional compass positions were added by simply plotting the visually observed direction of compass north on a photograph of the rock. The results of these observations are shown in Figure 15. This figure shows the top of Lightning Rock as viewed from the west. Dots indicate the points where compass observations were recorded. The attached lines show the direction of magnetic north, indicated by the compass at that point. The two lines radiating from the same dot (near the right-hand edge of the figure) represent two separate observations of the compass north direction at that point. The lines associated with the dots at the extreme left of the figure show the direction of the local undisturbed magnetic north on the top of the rock. Note that the lines indicate only the *direction* of compass north; they do not indicate the strength of the magnetic field. Some lines have been drawn shorter than the others simply to avoid overlapping with other observations.

Figure 15 shows that as the compass is moved southwestwards parallel to the northwest edge of the top, a deviation in the direction of compass north of 70°–120° occurs when the compass reaches the northernmost of the parallel petroglyph lines, which

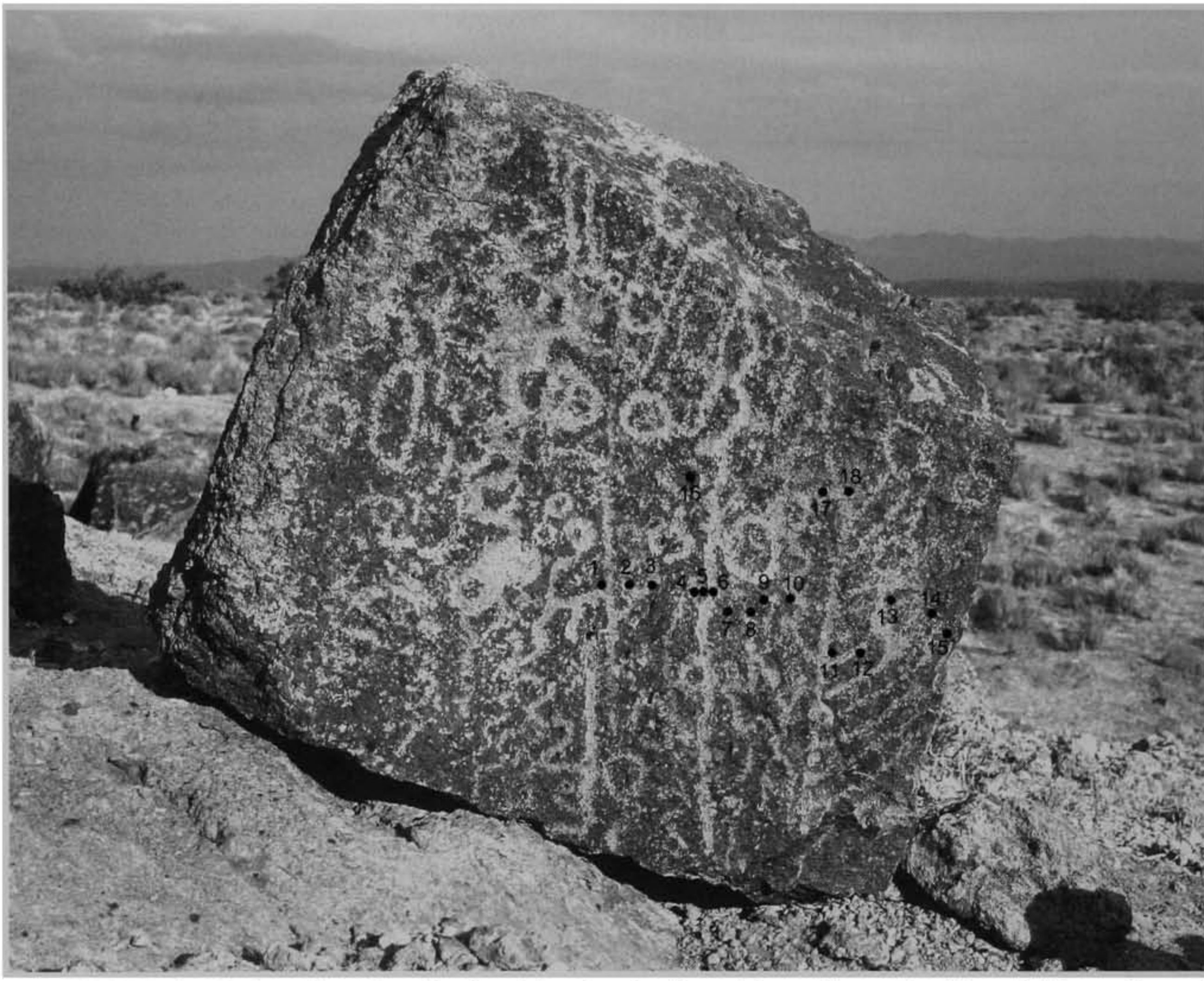

Figure 14. Lightning Rock, northwest face. Numbered dots show locations of observations made with small (19-mm. diameter) compass, listed in Table 3.

lies along or just to the right of the locus of maximum south-attracting magnetization of discharge path 1. Continuing southwestwards, the behavior of the compass becomes complex, with the deviations dependent upon the proximity of the compass to the north- and south-attracting loci of paths 1 and 2, and the interplay of these fields with the earth's magnetic field. Deviations cease once the compass passes the third parallel petroglyph line, or (very close to the northwest edge of the top) the fourth of these lines; these lines coincide with the locus of the north-attracting maximum of path 2. Outside this region, only three areas of greatly deviant compass directions were detected: (1) at a point near the northwest edge and midway between the south- and north-attracting maxima of path 3; (2) in the center of the circular petroglyph which lies between the south- and north-attracting maxima of path 4; and (3) near the petroglyph line coinciding with the north-attracting locus of discharge path 6.

On the southwest face, discharge path 6 has a field strength of about 0.2 gauss, producing total deviations in both the large and small compasses of only about 10°, and (as discussed earlier) no detectable deviation in the lodestone. Consequently, it is unlikely that the native observers would have been able to detect this portion of the path from the anomalous magnetization. On the southwest face, path 6 would have had to have been detected by observing the actual strike or changes in the surface of the rock produced by the discharge, as on the lightning-trace rock discussed earlier. As indicated above,

Figure 15. Lightning Rock. Portion of top, looking east-southeast. Dots show locations where small (19-mm. diameter) compass was placed on rock surface. Attached lines show direction of magnetic north indicated by the compass at that point. Lines radiating from dots at the far left and far right show the local direction of magnetic north, undisturbed by the magnetic anomalies due to the lightning strikes. The two lines originating from the same dot near the right-hand edge of the figure indicate the compass north directions from repeat observations at that location.

there is a single, heavily-patinated petroglyph on this face, consisting of three concentric circles and a straight line, as shown in Figure 6a. These circles have diameters (of their outer edges) of 11.0, 14.0, and 21.5 cm. respectively. The straight line descends vertically from the bottom of the innermost circle for a distance of 27.0 cm. The extreme patination of this petroglyph clearly shows that this symbol predates by many centuries the other (lightly patinated, and thus more recent) petroglyphs on the northwest face and top of Lightning Rock. In addition, while the petroglyph and discharge path 6 are superimposed, the symbol is not centered either on one of the lines of magnetic anomaly or on the center line of the discharge path; the south-attracting locus of the path passes about 11 cm. to the right of the center of the circles. It appears most likely, therefore, that this superposition is accidental, and that the petroglyph is unrelated to the lightning discharge.

The lodestone and compass observations of both the northwest face and the top of Lightning Rock demonstrate that Native American observers lacking compasses could indeed have detected at least some of the magnetic anomalies present on the surface of Lightning Rock. Moreover, the fact that only certain of the anomalies coincide with petroglyph lines would appear to further support the conclusion that they were not only detecting magnetic anomalies, rather than lightning strikes, but were using a lodestone to do so. All of the petroglyphs on the top of Lightning Rock mark locations where significant compass (and presumably lodestone) deviations occur, while on the northwest face only those anomalies that produce complete reversals in the direction of the lodestone or compass axis are marked. The other anomalies, both on the northwest and southwest faces and (with one exception) on the top, produce little or no lodestone or compass deviations and have no clearly associated petroglyphs. These anomalies might either have not been detected by the observers, or might have been considered of less interest or importance, since they produced only slight changes in the orientation of the lodestone.

It might be argued that—considering the large number of petroglyphs that are present on the northwest face of Lightning Rock—some coincidences in the positions of the petroglyphs and the magnetic anomalies would be expected. However, an examination of these petroglyphs shows that out of the 70 or so elements on the northwest face, only a few consist of strongly inscribed vertical lines. Only two of these extend over a large portion of the face, and it is just these two that mark those loci of maximum north-attracting anomalous magnetization that have the most dramatic effects on the lodestone. The importance of one of these lines (that coinciding with the north-attracting locus of path 4) appears to have been emphasized by the addition of the curved branches on either side of it. On the top of the rock, the chance of coincidence is even less likely, since only a few petroglyphs are present, and all of these are associated with magnetic anomalies that produce significant deviations in the direction of compass north.

Overall, then, the evidence would seem to indicate that at least some of the petroglyphs on the top and northwest face of Lightning Rock were inscribed because magnetic anomalies were discovered on these surfaces using a lodestone as a detector, even though no published references to the use of lodestones by American Indians have so far been located by the writer. Certainly the present study does show that such observations were technologically possible for the observers at Lightning Rock.

The meanings of the other petroglyphs that do not mark the anomalies are uncertain. Perhaps these elements, consisting mainly of circles and wavy lines, were intended to in some way celebrate or memorialize the unusual—or even "magic" (i.e., magnetic)—properties of Lightning Rock.

If magnetic anomalies were detected on Lightning Rock, why were they not also detected on the other three rocks in the boulder field that have lightning induced remnant magnetization? At the pyramidal rock shown in Figure 1, the greatest deviation of the large compass is about 30°. However, 180° reversals of both the small compass and the lodestone are observed for the south-attracting anomaly. At the lightning-trace rock (Fig. 3), a lodestone deviation of 90° was observed for the eastern discharge path, as well as a complete reversal of direction for the left-hand edge of the western path. These observations were difficult to make owing to the overhang of the rock face. In order to have the lodestone close to the rock surface, the length of the suspending fiber had to be kept very short. In these tests, a thread length of only 5 cm. was used. If the flexibility of the support fiber used by the natives was less than that of the thread, they might not have had sufficient instrumental sensitivity to detect the anomalies. In the case of the third rock, the discharge path is on the vertical south face of the rock and is of sufficient strength ($\Delta F = 0.65$ gauss, width: 21.5 cm.) to produce a complete reversal of the direction of the needle of the small compass and a total deviation of 50°, both with the large compass and with the lodestone suspended on a thread 25 cm. in length; therefore, detection by the native observers should have been possible. Thus, in the case of at least two of these other three rocks, either the observers simply failed to find the anomalies, or the lightning strikes occurred after the observers were active in the area.

While the case for the detection of the anomalous magnetization by Native Americans appears quite strong, it would be premature to reach any definite conclusion on the basis of only this one example. The present observations may, however, provide an indication of phenomena to be watched for in future field investigations.

SUMMARY

Lightning-induced magnetism in rocks can be easily recognized from its characteristic pattern of two, more-or-less parallel, lines of maximum anomalous magnetization, which have opposite polarities. These lines mark the edges of the discharge, which occurs as a ribbon of current across the surface of the rock. The direction of the lightning current is indicated by the polarities of the lines. When facing in the direction of the electron flow, the north-seeking end of the compass needle is attracted to the rock face on the left-hand side of the discharge path, and the south-seeking end to the right-hand side. In at least some instances, the passage of a lightning current over the surface of volcanic tuff can produce a change in the appearance of that surface, the width of this marking equaling the separation of the lines of maximum anomalous magnetization delineating the edges of the discharge ribbon. This marking may be obliterated in time on surfaces that are not protected from the weather.

The observations of "Lightning Rock" indicates that this rock was struck at least twice by lightning, resulting in a total of seven discharge paths across the top and down the sides of the rock. The northwest face of Lightning Rock is thickly inscribed with petroglyphs. The present study suggests that these petroglyphs, together with the few present on the top of the rock, are related to the lightning discharges. They further suggest that the Native Americans used a lodestone to detect and mark certain of the magnetic anomalies, rather than observing the actual lightning discharges when they occurred and/or the physical traces left on the rock surface.

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