Anasazi Solar Marker: The Use of a Natural Rockfall

Abstract. *The midday "sun dagger" solstice and equinox marker on Fajada Butte in Chaco Canyon, New Mexico, is formed by three sandstone slabs that collimate sunlight onto two spiral petroglyphs. The slabs appear to be the result of a natural rockfall and not a construct of the Chacoan Anasazi. Although neither the rockfall nor the petroglyphs can be dated accurately, it is likely that the petroglyphs were designed after the rockfall by people who observed the details of the light pattern for several annual cycles.*

Studies in the American Southwest suggest the importance of astronomical observations for ritual and agricultural calendars, particularly to the agrarian Puebloan peoples. These peoples recorded the rising and setting points of the sun by using both natural horizon marking stations and masonry or adobe buildings (*1*). Both types of "observatories" were used by prehistoric peoples in the American Southwest, particularly by the Anasazi of the Colorado Plateau (*2*).

A number of Anasazi sunrise and sunset recording stations have been identified in the Chaco Canyon region of New Mexico (*2, 3*), but a midday solar observation marker, located on Fajada Butte in Chaco Canyon, is the first to be discovered in the Southwest (*4*). The marker (Fig. 1) consists of three sandstone slabs which stand on edge and fan out at high angles to a cliff face, collimating sunlight onto two spiral petroglyphs on the cliff face behind the slabs.

It has been suggested that this marker is a sophisticated instrument, designed and built sometime during the 10th or 11th centuries A.D. (*4*), a period of cultural florescence in the Chacoan area. Because there is a significant difference between the level of skills required to conceive and construct a midday solar marker and those required to discover, observe, and use a natural one, the origin of the solar marker is important to our interpretation of cultural development in Chaco Canyon. The sandstone slabs of the solar marker have a natural appearance (*5*) and are similar in form and rock type to numerous eroded blocks observed at the bases of cliffs throughout the Chaco Canyon area (Fig. 2); this suggests that the slabs were emplaced by a natural rockfall, not by the Anasazi.

The architectural style in Chaco Canyon in the 10th and 11th centuries employed a core and veneer masonry with small, well-shaped sandstone tablets and blocks. Although buildings were multistoried and other architectural features such as ramps were massive, megalithic construction has not been reported. The largest of the solar marker slabs is approximately two orders of magnitude heavier than the typical Chacoan building stone and five times heavier than the largest known building block—a roof foundation disk located at Chetro Ketl,

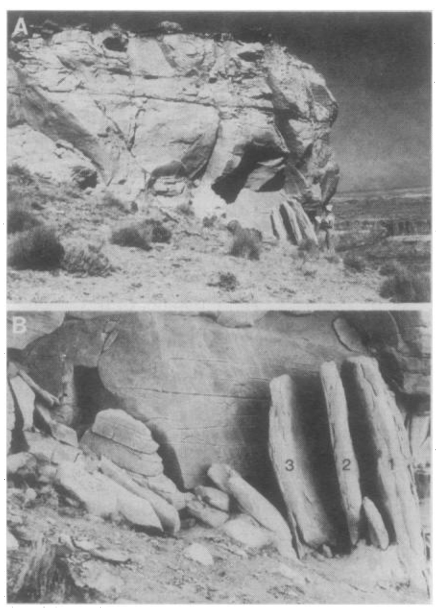

Fig. 1 (left). Two views of the geologic setting of the solar marker. (A) The top 10 m of the Cliff House Sandstone on Fajada Butte in Chaco Canyon, New Mexico, showing horizontal bedding, crosscutting joints, the sloping ledge, and solar marker slabs. Note the alcove extending above and to the left of the solar marker. (B) The three large almost vertical sandstone marker slabs. They appear to have been emplaced naturally from a source within the alcove above them and to their left. The relatively recent rockfall to the left indicates that the process of disaggregation is continuing and suggests a mechanism for the removal of other material before the marker slabs rotated and fell.

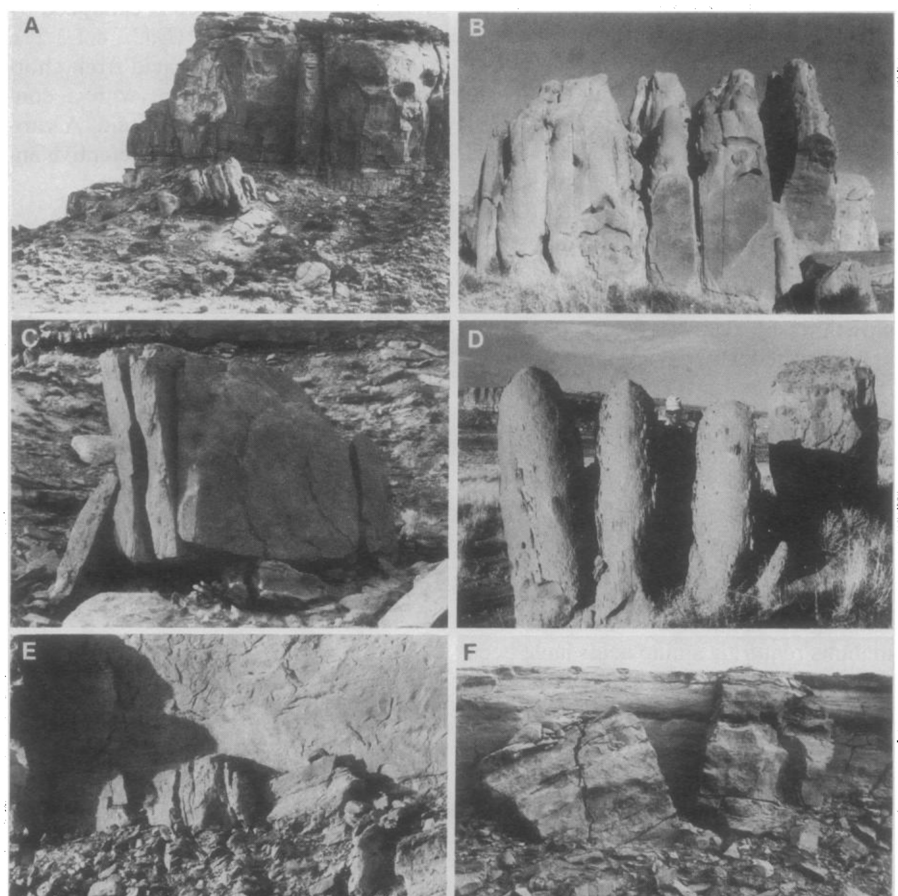

Fig. 2 (right). Examples of naturally fallen blocks of Cliff House Sandstone in Chaco Canyon. (A) Typical cliff showing vertical joints, weaker zone at base, fallen blocks, and detritus. (B) Large block split along bedding planes; slightly rounded edges indicate moderate weathering. Surface of slab on far left is similar to those of solar marker slabs. Note petroglyphs on central slabs. (C) Relatively recent fall indicated by sharp edges. Note rotation of slabs. (D) Relatively ancient fall indicated by heavily weathered block showing large gaps. (E) Two fallen blocks leaning against the cliff; one has maintained its horizontal orientation whereas the other has rotated to a nearly vertical orientation. (F) Rotated block leaning against a cliff.

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one of the Anasazi building complexes. Furthermore, foundations are common in Chacoan architecture, but no foundation is evident for the solar marker.

Chaco Canyon is bounded by cliffs that are capped by the Upper Cretaceous Cliff House Sandstone, a cliff-forming, predominantly sandstone unit that varies from thin- to thick-bedded to massive, contains lenses or tongues of shale, and is porous and mechanically weak (*6–8*). The solar marker is in a shallow alcove about 10 m below the 115-m high summit of Fajada Butte, an outlier of Cliff House Sandstone that has been isolated by erosion from Chacra Mesa. The marker slabs rest on a moderately sloping (20° to 27°) colluvium-covered ledge that has developed on interbedded shale and sandstone within the formation (Fig. 1A).

The cliffs of Fajada Butte are typical of the cliffs forming Chaco Canyon. Fallen blocks that have split, weathered, or both, along bedding planes into subparallel slabs are common throughout the canyon. Several of these slabs are oriented at high angles to the canyon wall, and a few are in contact with the wall (Fig. 2). The blocks range from fresh to highly weathered, indicating that processes of cliff erosion have been continuous.

The position of one block (Fig. 2F) may have resulted from sliding and rotating about an axis roughly perpendicular to the adjacent cliff wall. Such a mechanism could result in an orientation similar to that of the marker slabs.

Schumm and Chorley (*8*) have suggested that the process preceding the rapid fall of Threatening Rock from the cliff behind Pueblo Bonito in 1941 may have taken 2500 years and involved settling, tilting, and sliding. They recorded the movement of this rock for the 5 years before its fall and described five steplike patterns of alternating rapid and slow movement. The most rapid movement occurred between the first and last killing frosts.

Examination of the shape and sedimentary structure of the rear surfaces of the solar marker slabs indicates that they most likely originated within the alcove to the left and above their present position (*9*). Matching concretions on adjacent faces of the three slabs indicate that they were once part of one block that split along bedding planes and there has been some weathering of the bedding plane surfaces. The slabs are spread out by 13° and 20° around a vertical axis. In addition, slab 3 (Fig. 1B) has been translated forward and upward about 15 cm with respect to slab 2. Slab 2 has been rotated about 12°, top forward, with respect to slab 1. This relative rotation is consistent with the apparent failure on impact of the lower front corner of slab 2 (Figs. 3 and 1B).

The alcove in the cliff marks a zone of weakness in the rocks (Fig. 1A). The alcove is bounded on the top, on each side, and to the rear by joint surfaces (*10*), and on the bottom by the boundary between the more massive sandstone and a layer of weaker, thinly bedded sandstone and shale. The rock that once filled the alcove presumably weathered away (*11*) or crept down the sloping ledge and fell over the cliff's edge. With loose material removed from the alcove and with the cliff undercut along the weak zone, the block may have slowly rotated, slipped, and fallen from the source region to the present location of the marker slabs. Schumm and Chorley (*8*) suggest that failures producing rockfalls are probably preceded by movements of progressively increasing magnitude. The annual freeze-thaw cycle provides a natural mechanism for facilitating motion. We propose the initial slow rotation of a large block, such as was observed elsewhere in Chaco Canyon, followed by a sudden fall that split the block into the marker slabs (Fig. 4). Any surficial scraping of the cliff face or slabs that may have occurred during the fall

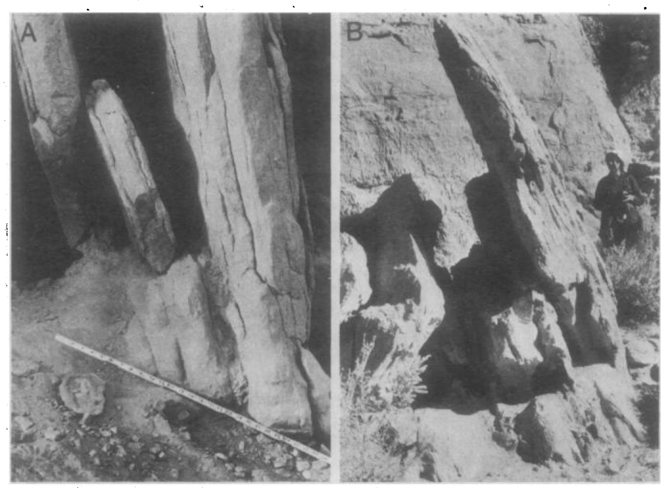

Fig. 3. Weathered bases of sandstone slabs showing the preferential removal of material along bedding planes and the collection of unconsolidated debris. (A) The base of solar marker slab 2 (Fig. 1B) that probably broke on impact. (B) A comparable upturned block elsewhere in the canyon with similarly weathered surfaces.

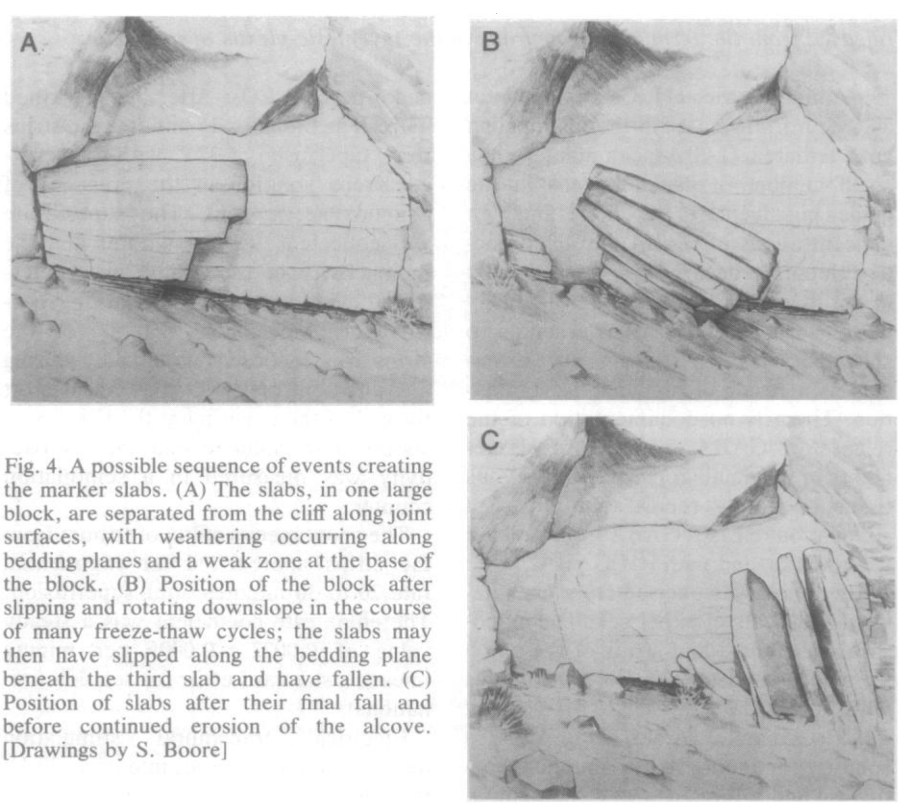

Fig. 4. A possible sequence of events creating the marker slabs. (A) The slabs, in one large block, are separated from the cliff along joint surfaces, with weathering occurring along bedding planes and a weak zone at the base of the block. (B) Position of the block after slipping and rotating downslope in the course of many freeze-thaw cycles; the slabs may then have slipped along the bedding plane beneath the third slab and have fallen. (C) Position of slabs after their final fall and before continued erosion of the alcove. [Drawings by S. Boore]

would have been obliterated rapidly by weathering.

The appearance of the solar marker slabs strongly suggests natural emplacement; their position does not require moving and setting by humans. Although it is not possible to reconstruct a detailed history of the slabs, we conclude that a rockfall probably occurred, that light patterns were observed, and petroglyphs were added to develop the solar marker.

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9. We generally agree with the source proposed by Sofaer *et al.* (*4*) but not that a precise location, to within 1 cm, can be determined.
10. W. C. Bradley, *Geol. Soc. Am. Bull.* **74**, 519 (1963). The rear surface is probably an exfoliation joint; such joints commonly run parallel to cliff faces in Chaco Canyon.
11. S. A. Schumm and R. J. Chorley [*Z. Geomorphol.* **10**, 11 (1966)] argue that the general lack of talus blocks below the retreating sandstone cliffs of the Colorado Plateau (including the Cliff House Sandstone) is the result of rapid weathering of the blocks.
12. We thank Superintendent W. Herriman and the staff at Chaco Culture National Historical Park for their cooperation and D. McCulloch, D. Rubin, R. Webb, and H. Wilshire for their assistance in the field.

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Release of γ-Aminobutyric Acid from Cat Colon

Abstract. *The release of γ-aminobutyric acid was confirmed in isolated cat colon loaded with tritiated γ-aminobutyric acid. Thirty to 180 minutes after loading the spontaneous efflux of tritium appeared to fit a single exponential curve with an efflux rate coefficient of 0.002 per minute. Electrical stimulation produced frequency-dependent increases in the tritium efflux and in the contractions. Even 120 minutes later over 91 percent of the total radioactivity in the superfusates was attributable to tritiated γ-aminobutyric acid. The acid release and the contractions induced by electrical transmural stimulation were inhibited by tetrodotoxin and by a calcium-free medium. Release of the acid was not significant during contractions elicited by nicotine and acetylcholine. These findings indicate that γ-aminobutyric acid is released from the terminals of neurons in the myenteric plexus of the colon.*

γ-Aminobutyric acid (GABA) may act as a neurotransmitter in the mammalian gut. Tritiated GABA accumulates in a small number of ganglion cells in the guinea pig myenteric plexus (*1*), and high concentrations of GABA and highly active glutamate decarboxylase are present in the myenteric plexus (*2*). In identifying a neurotransmitter, it is essential to show that it is released from nerve terminals as a result of presynaptic stimulation. There is no documentation of the release of GABA from neuronal elements in mammalian peripheral nervous tissue. We now report that electrical stimulation releases GABA from isolated cat colon loaded with [^{3}H]GABA.

The colon was excised from anesthetized adult cats of either sex. The mucosa was removed and strips of the colon were incubated at 37°C for 40 minutes with $5 \times 10^{-8}M$ [2,3-^{3}H]GABA (1 mCi/ml, 57 Ci/mmole) (Amersham) in Krebs solution containing $10^{-5}M$ aminooxyacetic acid and saturated with 95 percent O_2 and 5 percent CO_2. After being washed in fresh medium for 15 minutes the strips were superfused at 37°C with oxygenated Krebs solution in the presence of aminooxyacetic acid. The superfusate was collected every 2 minutes and the radioactivity of the sample was determined with a liquid scintillation spectrometer. Mechanical activity of the strips was recorded isotonically during measurement of [^{3}H]GABA release. At the end of the experiment the tissue was dissolved in Soluene and the radioactivity was measured in a scintillation counter.

The spontaneous efflux of tritium from the strips approached an exponential rate 20 to 30 minutes after superfusion. The efflux rate coefficient was a steady value of 0.0022 ± 0.0003 per minute (mean ± standard error for ten determinations).

Electrical transmural stimulation (pulse duration, 1 msec; intensity, 30 V; frequency, 1 to 20 Hz) for 1 minute resulted in a significant increase in ^{3}H efflux above the spontaneous release occurring during the period before stimulation. The efflux was accompanied by contraction of the preparation (Fig. 1a). The responses to electrical stimulation were frequency-dependent, and both the increase in ^{3}H efflux and the contraction were maximal at a frequency of 10 Hz. The frequency-response curve for electrically stimulated ^{3}H efflux was in good agreement with that for contraction (Fig. 1, b and c).

To confirm that the radioactivity in the superfusate was indeed GABA or its metabolites, superfusates from electrically stimulated and nonstimulated tissues were collected and 100-μl portions with added unlabeled GABA were subjected to high-voltage electrophoresis on Whatman 3-mm chromatography paper (*3*). GABA was identified with ninhydrin and the radioactivity of GABA was determined in a scintillation counter. Over 91 percent of the total radioactivity in superfusates from both electrically stimulated and nonstimulated samples proved to be [^{3}H]GABA, even after 120 minutes. Accordingly, the estimates of total radioactivity reported here appear to provide a satisfactory index of the level of unchanged GABA.

The effects of tetrodotoxin on the contractile response to 1 minute of electrical stimulation (1-msec pulses, 30 V, 1 to 20 Hz) were then investigated. Tetrodotoxin at the concentration of $10^{-6}M$ abolished the contractions induced by electrical stimulation at frequencies of 1, 3, and 5 Hz, indicating that the contractions were neurogenic in origin. On the other hand, the contractions induced by stimulation at 10, 15, and 20 Hz were not abolished by $10^{-6}M$ tetrodotoxin, suggesting that stimulation at frequencies over 10 Hz produced contractions not only by nerve stimulation but also by direct stimulation of the muscle. Therefore, in further GABA release experiments, 1-minute electrical stimulation with 1-msec pulse duration, 30-V intensity, and a frequency of 5 Hz was used.

The efflux of GABA from tissue in response to depolarizing stimuli often serves as an index of GABA release from nerve terminals into the synapses. However, elements other than nerve terminals also become depolarized during stimulation, and GABA is released from these elements. High concentrations of potassium or electrical stimulation releases [^{3}H]GABA from glial cells in the dorsal root ganglia (*4*), superior cervical ganglia (*5*), and brain (*6*). In our preparations the smooth muscle cells, nerves, blood and lymph vessels, mast cells,