

UC Merced

Journal of California and Great Basin Anthropology

Title

A Simple Method of Determining Archaeoastronomical Alignments in the Field

Permalink

<https://escholarship.org/uc/item/7vd4h0xw>

Journal

Journal of California and Great Basin Anthropology, 1(1)

ISSN

0191-3557

Authors

Seymour, Timothy P
Edberg, Stephen J

Publication Date

1979-12-01

Peer reviewed

A Simple Method of Determining Archaeoastronomical Alignments in the Field

TIMOTHY P. SEYMOUR
STEPHEN J. EDBERG

EDITOR'S NOTE: While it is not normally our policy to publish papers of a purely methodological nature, the following paper is useful to archaeologists with an interest in archaeoastronomy and can be employed in making observations of the type described in the preceding paper.

BECAUSE of the recent interest on the part of archaeologists in the possible astronomical significance of various archaeological features, field archaeologists are beginning to look for possible archaeoastronomical alignments with ever-increasing vigilance. This awareness has resulted in a number of notable discoveries in the past several years and promises many more as research continues. However, archaeologists in the field face a number of problems in their efforts to identify and describe such sites, not the least of which has been their general unfamiliarity with mathematical astronomy. Clearly, a means whereby the archaeologist himself could quickly calculate such alignments is sorely needed. Such calculations would in no way supercede field observations, but would provide a method of making those observations vastly more efficient.

As an aid in achieving this goal, we have developed the following simplified algebraic expressions, derived from spherical trigonometry, which can be used to determine whether or not a celestial object (such as the sun, moon, or particular star) of possible significance will rise or set at a point on the horizon indicated by an apparent alignment. The only field equipment required consists of a surveyor's transit, a book of trigonometric tables or hand calculator with trigonometric functions, and an inexpensive star atlas. In addition, a great deal of preliminary analysis can be accomplished prior to going into the field with nothing more complex than a topographic map and a protractor.

Two equations are used in the calculations; one is a simplified version of the other. Which equation is more appropriate will depend upon the topographic conditions prevailing at the site. Equation (1) can be used for sites located in very flat terrain where there are no hills, "obstructions," or depressions. These features should not exceed about 7° from the level mathematical or astronomical horizon which the observer would see if the earth were a smooth sphere. Equation (2) should be used when more uneven topography must be taken into account.

(1) $D = \sin^{-1}(\cos L \cos A)$

(2) $D = \sin^{-1}(\cos H \cos A \cos L + \sin H \sin L)$

The various letters used in the preceding equations can be interpreted as follows:

D is the declination (celestial latitude) of the hypothetical heavenly object (sun, moon, star) whose rising or setting point is indicated by the alignment.

L is the latitude of the site.

A is the azimuth direction, in degrees, the alignment is pointing, measured

clockwise from true north (see Fig. 1a).

H represents either the apparent height of any horizon obstruction such as a hill or mountain, in positive degrees, or any depression of the horizon below the astronomical horizon, in negative degrees (see Fig. 1b).

Procedures for employing the foregoing equations are explained in the following examples.

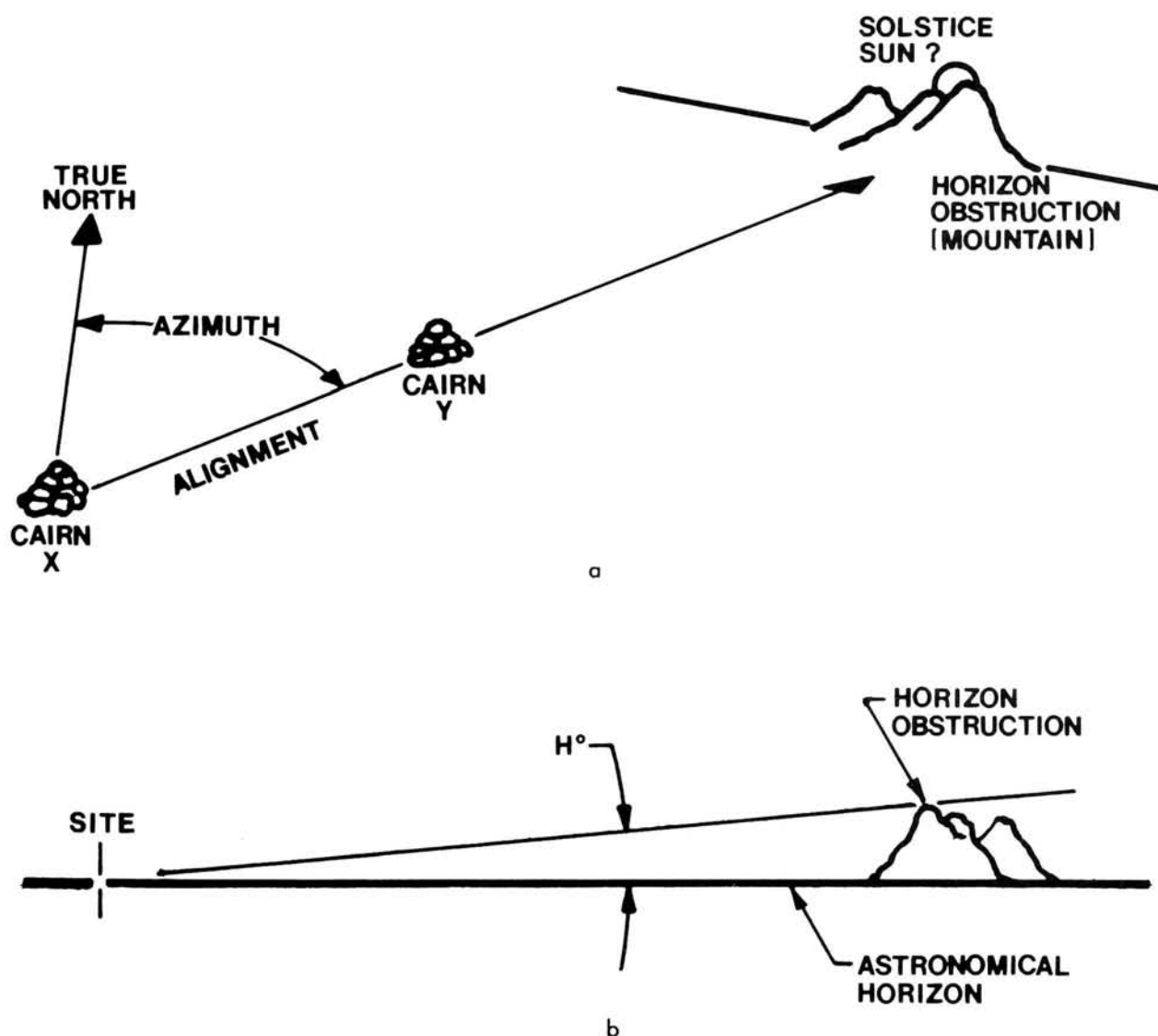


Fig. 1 (a & b). Hypothetical alignment showing the proper determination of the azimuth and H angles.

Example 1. An archaeologist suspects that a rock feature at a site is significantly aligned with a distant mountain peak, and hypothesizes that the sun may rise behind the peak on the morning of the summer solstice. His hypothesis can be quickly checked as follows. First, the azimuth (\underline{A}) of the alignment is measured with a compass or transit and found to be $63^{\circ}54'$. Second, the latitude (\underline{L}) of the site, taken from a USGS quad sheet, is found to be $37^{\circ}30'$. Third, the apparent height (\underline{H}) or elevation of the mountain behind which the sun is suspected to rise is measured by transit and determined to be $+5^{\circ}$. Since the horizon is not flat and high accuracy is desired, equation (2) is selected. Substituting appropriate values into the equation gives the following results:

$$\begin{aligned} D &= \sin^{-1} [(\cos 5^{\circ})(\cos 63^{\circ}54')(\cos 37^{\circ}30') \\ &\quad + (\sin 5^{\circ})(\sin 37^{\circ}30')] \\ &= \sin^{-1} [(0.9962)(0.4400)(0.7934) \\ &\quad + (0.0872)(0.6088)] \\ &= \sin^{-1} [(0.3478) + (0.0531)] \\ &= \sin^{-1} (0.4009) \\ &= +23^{\circ}38' \end{aligned}$$

The sun's declination at the time of the summer solstice is $+23^{\circ}27'$. With a reasonable margin

of error, we may therefore assume that a significant alignment does exist in the situation described above. Since the sun's declination varies systematically from $+23^{\circ}27'$ at the summer solstice, to 0° at the equinoxes, to $-23^{\circ}27'$ at the winter solstice (as the earth moves through its yearly orbit), other alignments at other azimuth headings might be looked for. If there were alignments to the equinoxes or to the winter solstice, the declination values given by the equation would be $D = 0^{\circ}$ and $D = -23^{\circ}27'$. (Note that plus or minus values indicate whether an object is above or below—i.e., north or south—of the celestial equator.)

It should be recognized that alignments that point to objects rising on the eastern horizon may also be used to point to objects setting in the west. In this case the azimuth of the western alignment is simply the eastern azimuth plus 180° . The declination of the setting object, in this two-way situation, would be the same except for a change in sign. In the example just given, the declination of an object setting in the west in line with the rock feature would be $-23^{\circ}38'$ (rather than $+23^{\circ}38'$);

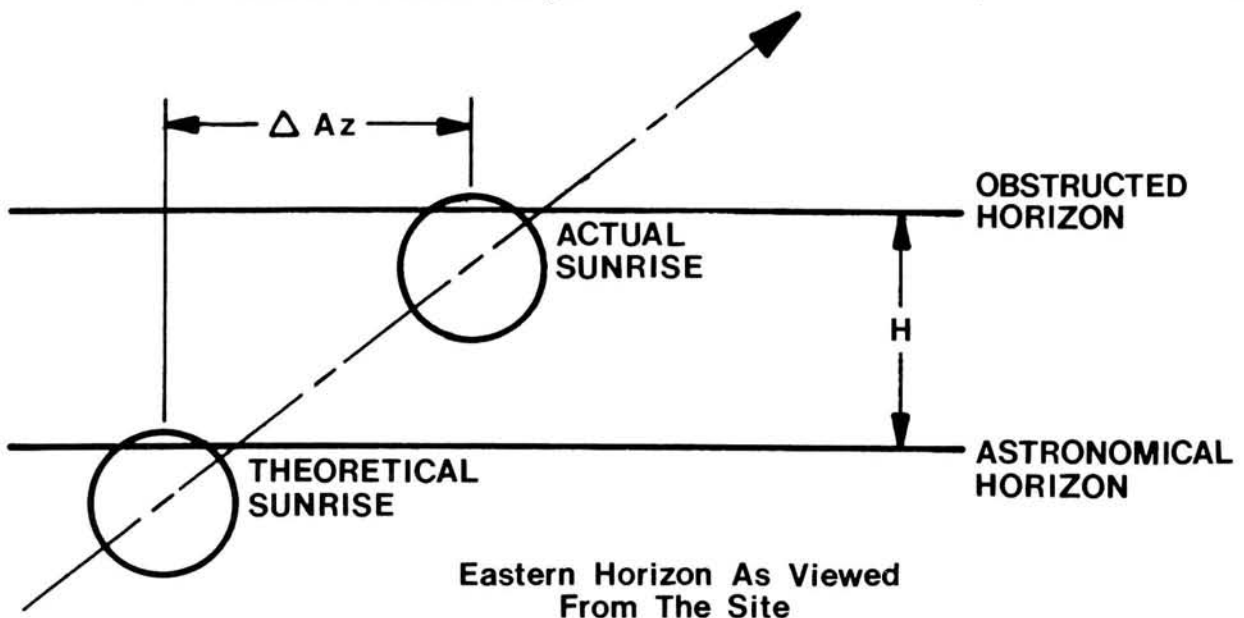


Fig. 2. Schematic of the rising sun showing the relationship between \underline{H} and azimuth.

this would correspond to the sun's setting position at the winter solstice. However, it should be noted that each declination value for the rising and setting horizon points may have to be calculated individually if each horizon has a different elevation or H value (see Fig. 2).

It should be emphasized that the major source of error in these calculations will arise from an inability to determine the azimuth heading of an alignment precisely. We caution that uncertainties in the direction of a possible alignment will result in a range of appropriate declination in the sky rather than a single value. The archaeologist must take this uncertainty factor (which will vary widely from site to site) into account when assessing the significance of an alignment.

Since alignments with the rising or setting solstice or equinox sun are usually the most common, it is often desirable to know in advance what azimuth headings to look for in alignments in a particular area or at a particular site to be examined. This can be done before going into the field by solving equation (1) or equation (2) for azimuth instead of for declination.

$$(1a) A = \cos^{-1} \left(\frac{\sin D}{\cos L} \right) \quad \text{or}$$

$$(2a) A = \cos^{-1} \left[\frac{\sin D - (\sin H \sin L)}{\cos H \cos L} \right]$$

This will provide a quickly calculated *estimate* of the pointing direction of any possible alignments. Once in the field, any such orientations can be precisely measured and calculated using the formal method given.

Such prior calculations of likely azimuth headings have a number of possible applications. They might conceivably be used to locate solstice sites associated with prominent mountain peaks by following the predicted azimuth on a USGS quad map east or west from the peak to a point of likely observation. A complementary type investigation (and perhaps a more immediately practical one)

would be to examine the possible association of nearby mountain peaks with already cataloged sites. This can be done by following the azimuth heading east or west from the site to ascertain if any likely topographic features lie along this line of sight.

All such calculations of azimuths have to take into account elevation differences between the site and mountain peak. This value (H) can be easily determined by using the quad map and employing a little high school trigonometry.

$$\tan H = \frac{\text{The difference in elevation between the mtn. peak and the site (in meters).}}{\text{The distance (in meters) between the mtn. peak and the site.}}$$

This simple tool can also be used to calculate reasonably accurate values for H when the researcher does not have access to a transit.

Let us now examine a situation where a site is located in flat terrain and there are no elevated features on the horizon.

Example 2. The alignment of two rock cairns at an archaeological site is suspected to have astronomical (particularly solar) significance. This hypothesis can be checked as follows. The azimuth (A) is measured as 52°03', while the latitude (L) is the same as in example 1 (37°30'). Substituting appropriate values into the equation gives the following results:

$$\begin{aligned} D &= \sin^{-1} (\cos 37^{\circ} 30') (\cos 52^{\circ} 03') \\ &= \sin^{-1} (0.7934)(0.5299) \\ &= \sin^{-1} (0.4879) \\ &= +29^{\circ} 12' \end{aligned}$$

Since the sun is never farther north than +23°27', this alignment clearly has no solar significance. However, the moon varies cyclically in declination between about +29° and -29°. Since many cultures were probably well aware of this cycle, we might postulate a lunar alignment in the example above. This would be difficult to verify unless there was an association with lunar symbols in rock art.

Similar outside corroboration will be necessary in situations where there is more than one possible celestial object associated with a particular declination. In the above example, a declination of $+29^\circ$ is also close enough to that of the star Beta Tau, given the uncertainties of azimuth determination, to make it another candidate.

Such alignments with bright stars are in some respects easier to ascertain than solar or lunar alignments, since the declinations of stars vary only slightly with time (i.e., over centuries) compared to those of the sun (over months) and moon (over days). Here, star charts such as *Norton's Star Atlas* (Norton 1973) or the *New Popular Star Atlas* (Inglis 1974) may be of more help (when used in conjunction with a table of stellar declinations) than a table alone (see Table 1). Once a possible declination has been calculated, the indicated parallel of declination line may be followed across the face of the star chart and all likely bright stars near it noted. This also facilitates the visualization of any other possible alignments with rising or setting constellations in the area. Such a procedure has been used by the authors to successfully identify alignments with the first and last rising "belt stars" in Orion at a site near Barstow's Ceremonial Point.

Like the sun and moon, the stars have a yearly motion that is known to have been employed for calendrical reckoning by ancient cultures around the world. Once a year (or for a few days once a year), each star rises in the morning, only to be quickly drowned in the glare of the rising sun. These "heliacal risings" of certain bright stars were often used to mark important yearly ceremonies and events. Since the verification of such observations offers great potential for determining seasonal activities at a site, we have included a simple method of determining such risings as a complement to the techniques already described.

The calculation of the *formal date of heli-*

TABLE 1

DECLINATIONS OF SELECTED BRIGHT STARS*

Decl.	Star	Name
+89°02'	Alpha Ursa Minoris	Polaris
+62°01'	Alpha Ursa Majoris	
+57°19'	Delta Ursa Majoris	
+56°39'	Beta Ursa Majoris	
+56°14'	Epsilon Ursa Majoris	
+55°11'	Zeta Ursa Majoris	
+53°58'	Gamma Ursa Majoris	
+49°41'	Alpha Persei	
+49°34'	Eta Ursa Majoris	
+45°57'	Alpha Aurigae	Capella
+45°06'	Alpha Cygni	Deneb
+44°57'	Beta Aurigae	
+38°44'	Alpha Lyrae	Vega
+32°00'	Alpha Geminorum	Castor
+28°34'	Beta Tauri	
+28°09'	Beta Geminorum	Pollax
+27°51'	Beta Cygni	
+23°58'		Pleides
+20°06'	Gamma Leonis	
+19°27'	Alpha Bootes	Arcturus
+16°27'	Delta Geminorum	
+16°25'	Alpha Tauri	Aldebaran
+12°13'	Alpha Leonis	Regulus
+08°44'	Alpha Aquilae	Altair
+07°24'	Alpha Orionis	Betelgeuse
+06°18'	Gamma Orionis	
+05°21'	Alpha Canis Minoris	Procyon
-00°20'	Delta Orionis	
-01°13'	Epsilon Orionis	
-01°58'	Zeta Orionis	
-05°09'	Beta Eridani	
-08°15'	Beta Orionis	Rigel
-09°41'	Chi Orionis	
-10°54'	Alpha Virginis	Spica
-16°39'	Alpha Canis Majoris	Sirius
-17°56'	Beta Canis Majoris	
-26°19'	Alpha Scorpii	Antares
-28°54'	Epsilon Canis Majoris	
-29°53'	Alpha Piscis Austr.	Fomalhaut
-47°11'	Gamma Velorum	
-52°40'	Alpha Carinae	Canopus
-56°50'	Gamma Crucis	
-57°29'	Alpha Eridani	Achernar
-58°28'	Delta Crucis	
-59°21'	Epsilon Carinae	
-59°25'	Beta Crucis	
-60°08'	Beta Centauri	
-60°38'	Alpha Centauri	
-62°49'	Alpha Crucis	
-69°48'	Large Magellanic Cloud	
-73°06'	Small Magellanic Cloud	

(Roth 1975:518)

*Epoch 1950

actual rising of a star (i.e., the date when the star and the sun's centerpoint rise at the same moment) can be simply accomplished as follows. Lay a protractor on the star chart in Fig. 3, with its center on the *celestial equator* and its flat edge (which represents the observer's horizon) perpendicular to this same equatorial line. The round edge of the protractor should be to the left. Rotate the protractor to 90° minus the site latitude (L), turning it counterclockwise for northern hemisphere sites and clockwise for southern hemisphere sites. Slide the protractor from right to left until the flat side intersects the star of interest. Read the date where the flat side intersects the *ecliptic*, which is marked for the sun's position on the first and fifteenth day of

each month. This is the date of the *formal* heliacal rising. The *actual* heliacal rising will be one or two weeks later because the sun must move away from the region of the star.

For example, to calculate the approximate heliacal rising of Deneb (Alpha Cygni) at a site located at 35° north latitude, rotate the protractor counterclockwise to $90^\circ - 35^\circ = 55^\circ$. Then slide the protractor along the celestial equator until its straight edge intersects Deneb (the brightest star in Cygnus) and read the approximate date where it also intersects the ecliptic. The estimated heliacal rising is about November 23rd. Note, however, that only the stars with names in Table 1 are likely candidates for use by prehistoric observers since only such very bright stars can be seen under

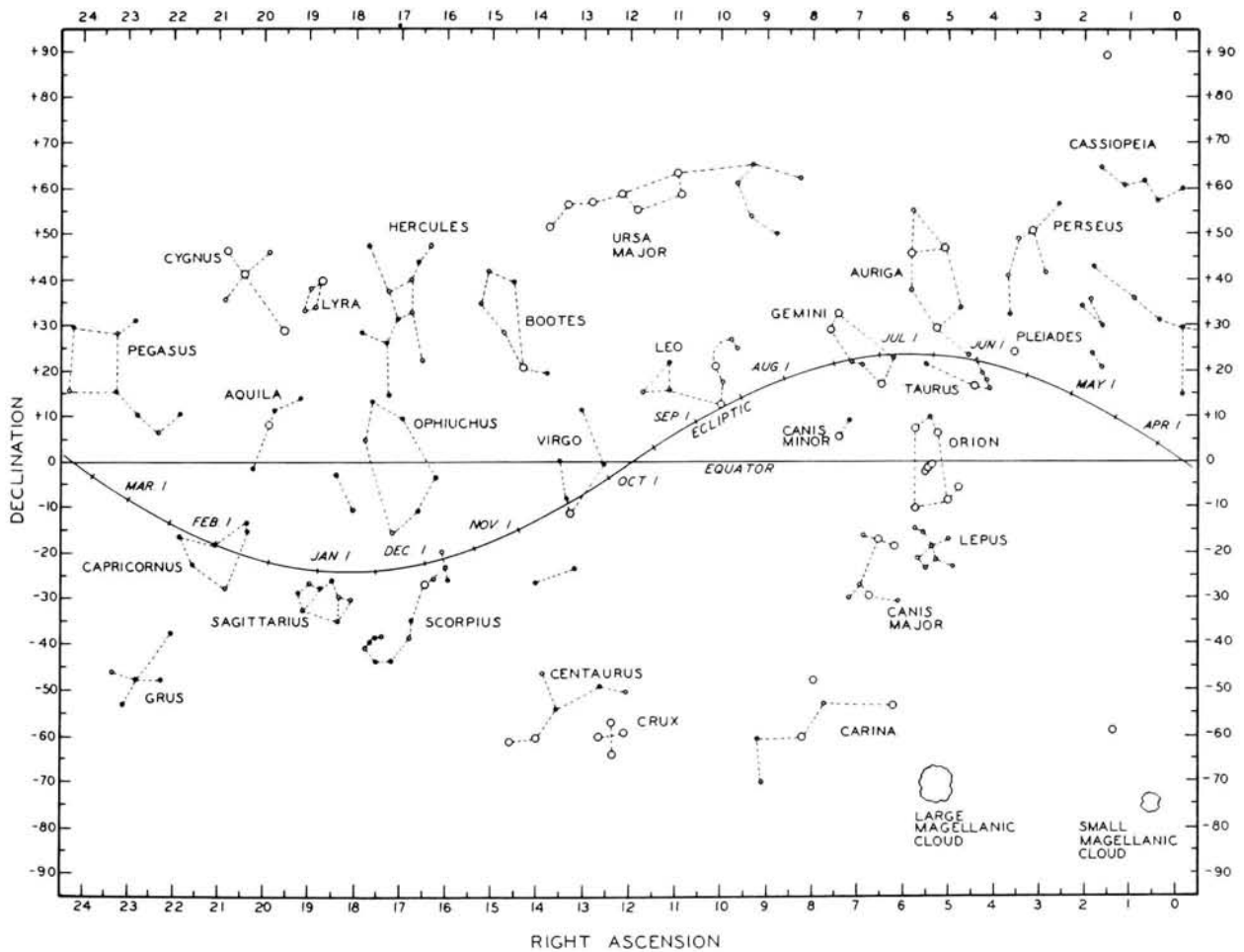


Fig. 3. Starchart of prominent constellations for determination of approximate heliacal rising dates.

heliacal rising conditions.

The accuracy of this method decreases the farther a star is from the celestial equator, since the protractor's flat side only approximates the curvature of the horizon and the modified mercator projection used on the chart distorts positions near the poles. Precessional effects have also changed the dates of heliacal risings over the centuries.

When using this method for determining the approximate date of heliacal rising, the observer should remember that stars with *positive* declinations of 90° minus the site latitude (L) or greater are always above the horizon (i.e., circumpolar), while those with *negative* declinations of 90° minus the site latitude (L) or lower are always below the horizon. In the southern hemisphere the situation is reversed: negative declinations are circumpolar and positive declinations never rise.

This paper has, of necessity, been brief. Further data, lists of new stars or other objects, or more complete tabulations may become necessary as the current state of knowledge advances. The method we have outlined does, however, provide an immediate and long-overdue tool for archaeologists dealing with ancient astronomies.

ACKNOWLEDGEMENTS

This report has benefited from the comments and advice of many individuals. Thanks go to Thomas Blackburn, Travis Hudson, and Ken Hedges for their encouragement and reviews of the early text. A similar debt is owed to Ed Krupp for his advice on astronomical problems, to Valerie Kramer, and to James Cleary and Gary Hartzell for their fine illustrations. Finally, thanks go to Robert Brown and Mike Morgan, who helped test out our theories in the field.

*California State Polytechnic University,
Pomona*

*San Fernando Observatory,
California State University, Northridge*

REFERENCES

- Inglis, R. M. G.
1974 *New Popular Star Atlas*. Sky Publishing Corp.
- Norton, Arthur P.
1973 *Norton's Star Atlas and Reference Handbook*. Sky Publishing Corp.
- Roth, G. D.
1975 *Astronomy: A Handbook*. Sky Publishing Corp.

