THE BALDWIN SOLAR CHART

By D. H. Baldwin
U. S. Geological Survey

DIRECTION, in terms of true bearing or azimuth, is one of the most important elements in all topographic mapping surveys.

The compass is of great value for showing direction in the many kinds of surveys in which its degree of precision is adequate; but before it can be used its angle of declination from true north must be known. Furthermore, the compass is not dependable in areas where there are local magnetic disturbances that cause erratic deflections in its pointings.

Early in the mapping operations of the Geological Survey an urgent need developed for some means to orient the plane table, an instrument used in graphic traverses, when used through areas where the compass needle does not serve. To meet this need, the "Solar Azimuth Chart" was designed in 1908; it worked as a sun dial with a movable vertical gnomon.

During the years of practical application of the chart to work in the field, experience has indicated some desirable changes in the original design. From time to time these changes have been incorporated into subsequent editions of the chart, but the principle upon which it works remains the same. This paper describes the latest edition of the Baldwin Solar Chart, with its supplement for use in the Tropics, as issued by the Geological Survey in 1943.

The familiar sun dial has a gnomon whose shadow-casting edge is parallel to the axis of the Earth. That is logical, since the purpose of the sun dial is to show hour angles measured around that axis. Any given hour angle of the sun is marked by a shadow at the same place on the fixed dial, regardless of the declination of the sun.

But the primary purpose of the Solar Chart is to mark direction, not time. Therefore, it is logical in this application to use a ruler with a vertical shadow-casting gnomon, because angles of direction are measured around the vertical plumb line as an axis. Such a vertical gnomon will always cast a shadow in the same direction for any given bearing of the sun, regardless of variations in other factors involved. Vertical refraction of the sun's rays has no effect upon the direction of this shadow.

The shadow of a vertical gnomon may be made to fall upon a horizontal surface where its direction may be observed to show the direction of the sun. By the usual methods of engineering astronomy, it is possible to forecast, for any chosen time and place, the direction of the sun in terms of an azimuth angle from the south. So suppose an arrow is drawn upon a piece of paper to represent north, and another one is drawn consistent with the calculated direction to the sun. At the chosen time and place the paper, resting on a horizontal surface, may be turned till this sun-arrow coincides with a shadow cast by a vertical gnomon. The first arrow will then point north.

To put this principle into practice the Solar Chart takes the place of the simple sheet of paper. Curves and scales printed upon it provide the means, graphically, to determine and indicate the sun's direction with respect to true north. The north-arrow still appears, but the sun-arrow is replaced by two points which would define its direction. These points, suitable for the circumstances of each individual observation, are found in a manner to be described later.

The observer must determine in advance the azimuth of the sun from his own position for the date and time of his observation. If the azimuth were to be computed, the following well-known formula might be used:

$$\tan Z = \frac{\sin t}{\cos t \sin \phi - \tan \delta \cos \phi}.$$

The variables involved are these: approximate latitude, and declination of the sun, to fix the observer's position on the chart; and the longitude and equation of time used to find sun time.

The skeleton diagram, given here, shows plainly how the chart depends upon the formula. The several parts of the formula are represented separately by actual dimensions used on the chart, as is indicated.

The user of the chart can obtain a solution in a short time, and by simple rules, without the use of a solar ephemeris or other tables. Practice makes it merely a mechanical operation.

For an observation at a given time and place, two points must be found on the chart; the sun-time point, and the pivot point. These two points are to be set in line with the shadow of the gnomon and the chart will then be oriented.

To find any sun-time point, it must first be clearly understood that the time required for use on the chart is local apparent or true sun time. It should thus be observed that corrections are to be applied to watch time for the equation of time and for the difference of longitude east or west from the center meridian of the time zone for which the watch is set.

The standard time meridians for the United States are at longitudes 75°, 90°, 105°, and 120° west of Greenwich, or 5, 6, 7, and 8 hours as expressed in time. Daylight-saving time at any given place is numerically 1 hour more than the standard time which it displaces and so requires a correction of minus 1 hour as well as the adjustments for the difference in longitude from the standard time meridian and for the equation of time as taken from Figure 2 on the chart.

The following instructions for using Figure 2 are quoted from the chart because they may be difficult to read in the reduced illustration:

> Figure 2, for equation of time, shows the number of minutes to add or subtract from local mean time to give corresponding sun time. This correction must be combined with the further correction of + or −1 minute of each 1/4 degree of longitude *east* or *west* of the meridian of the standard time in use. The result is the total correction to standard time to get sun time.

The sun time is to be plotted, consistent with the time scale, on the appropriate latitude curve in the main part of the chart. The latitude curves are drawn at intervals of 5°, but the dashed time lines indicate by the tips of the dashes the locus of curves for intermediate degrees of latitude.

A working pencil line for the proper latitude should be drawn so that sun-time points can be marked upon it, thus avoiding double interpolation. The curve should include the portion needed for times between 4:30 and 7:30, where the sun-time points will be located by using Figure 3, as explained on the chart. (Figure 3 is omitted on the Tropic Supplement.)

The sun time, plotted upon the interpolated latitude curve, locates the sun-time point.

During any single day the difference between watch time and sun time does not vary by any amount appreciable in the method. So when that difference is once obtained it may be used as a constant correction to the watch time without having to repeat the calculation for several individual observations made in a day's work.

Next, the pivot points must be determined, one for use in the forenoon, and another one symmetrically placed for the afternoon. These points are plotted in the center space of the north-arrow at the bottom of the chart. The distance

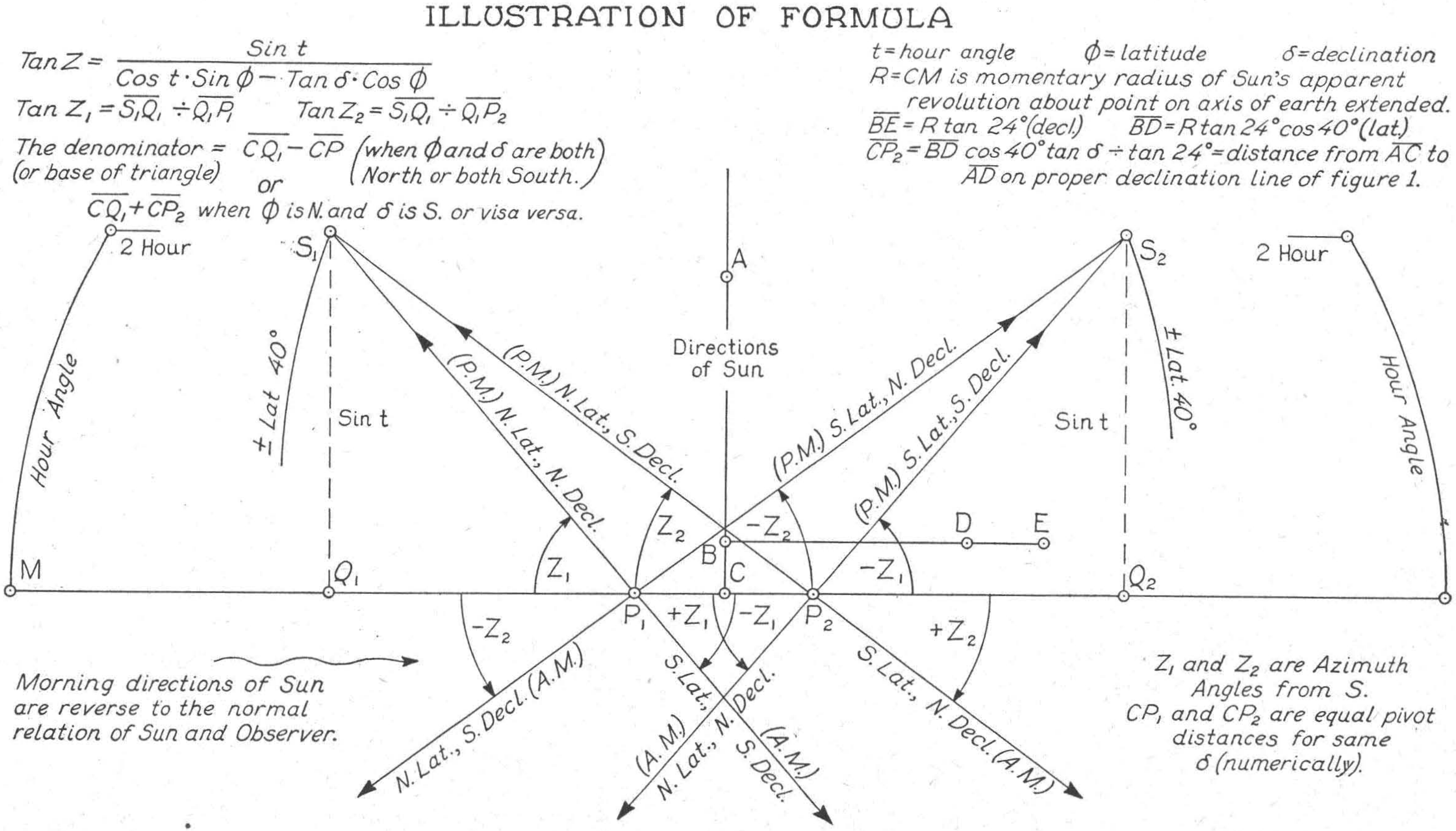

FIG. 1. The Baldwin Solar Chart.

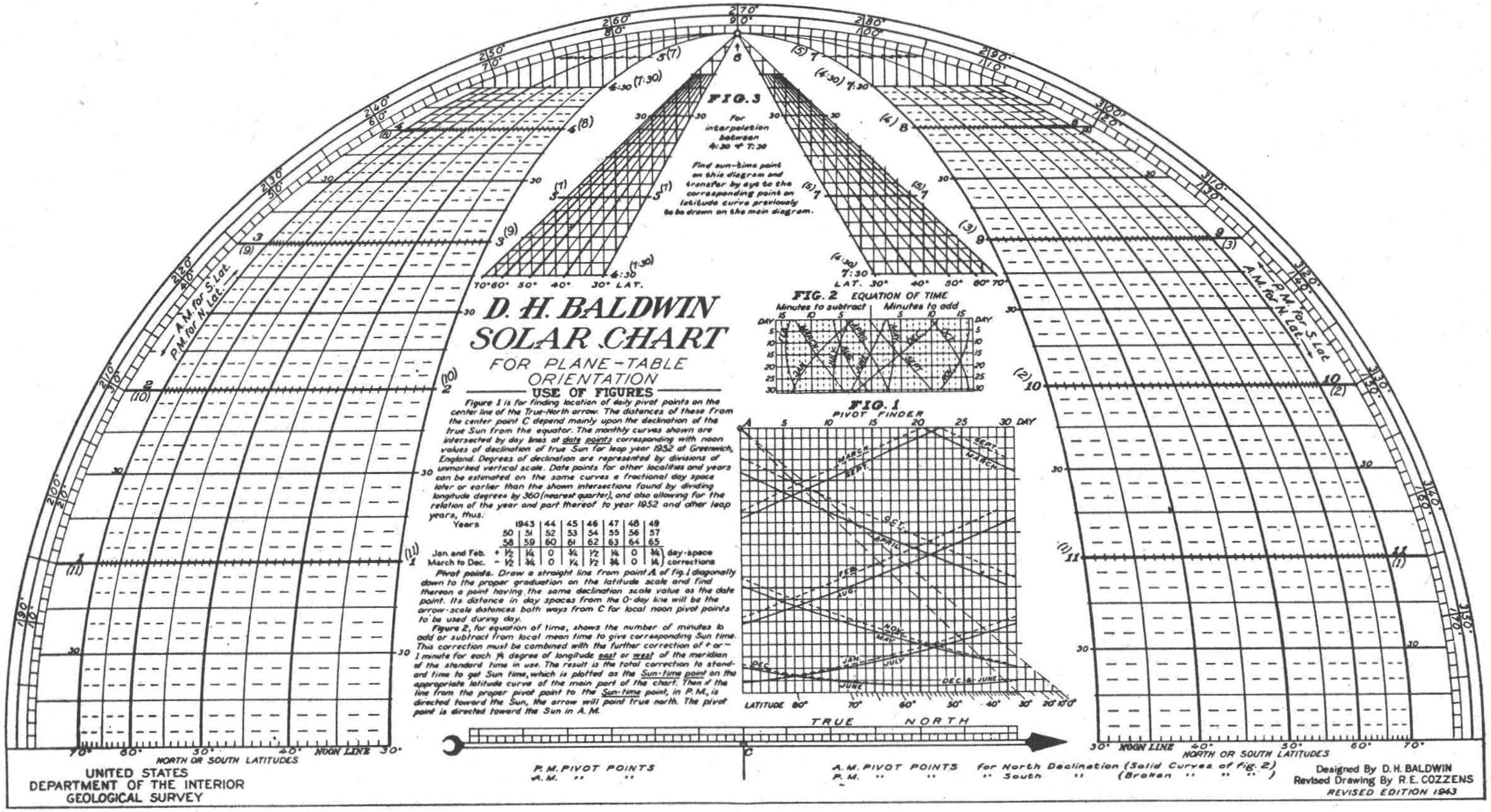

FIG. 2. Skeleton Diagram of Chart.

from C along the arrow to these points is dependent upon the sun's declination and the observer's latitude. Figure 1 is provided to determine graphically the distance necessary to plot the pivot points. The following instructions are quoted from the chart:

Figure 1 is for finding location of daily pivot points on the center line of the True-North arrow. The distances of these from the center point C depend mainly upon the declination of the true Sun from the equator. The monthly curves shown are intersected by day lines and *date points* corresponding with noon values of declination of true Sun for leap year 1952 at Greenwich, England. Degrees of declination are represented by divisions of unmarked vertical scale. Date points for other localities and years can be estimated on the same curves a fractional day space later or earlier than the shown intersections found by dividing longitude degrees by 360 (nearest quarter), and also allowing for the relation of the year and part thereof to year 1952 and other leap years, thus:

Years		1943	44	45	46	47	48	49	
	50	51	52	53	54	55	56	57	
	58	59	60	61	62	63	64	65	
Jan. and Feb.	+1/2	1/4	0	3/4	1/2	1/4	0	3/4	day-space
March to Dec.	−1/2	3/4	0	1/4	1/2	3/4	0	1/4	corrections

Pivot points. Draw a straight line from point A of Fig. 1 diagonally down to the proper graduation on the latitude scale and find thereon a point having the same declination scale value as the date point. Its distance in day spaces from the 0-day line will be the arrow scale distances both ways from C for local noon pivot points to be used during day.

When the pivot points and sun-time point have been plotted, the chart is ready to orient. The same working latitude lines may be used generally with sufficient accuracy for latitudes within 20 minutes of true latitude; otherwise new working lines will be required for a change in latitude.

It is to be noted that once the chart has been so prepared, the only change needed for successive observations during the day is to move the sun-time point along the latitude curve, according to watch time with a constant difference applied to it. This moving of the sun-time point involves no more delay than would be needed to allow a compass needle to settle, so the use of the chart is not time-consuming.

The design of the chart may be explained through the conception of a sun revolving around the earth's extended polar axis, in a plane which is north or south, according to the sun's declination, of the observer's position on top of the earth. The earth may be visualized as of insignificant size in comparison with the astronomic distances involved. The latitude curves are elliptical, because each one represents such a sun's nearly circular path seen in orthometric projection upon the horizontal plane through the position of the observer. The angle between the plane containing the sun's apparent path, and the horizontal plane is equal to the observer's co-latitude. Thus the sun's imaginary circular path is projected as an ellipse upon the horizontal plane; the ellipse is nearly a circle for high latitudes, and would be flattened to a simple straight line for an observer at the equator.

At times of zero declination the observer's position would appear at the center of such a projected ellipse. But at other times the sun seems to be following a circular path in a plane that is some distance either north or south of the observer. Consequently the projected path, the ellipse, will have its center either north or south of the observer's position. Then, the observer's relative position is moved north or south as the sun's declination changes south or north, thus preserving the proper working relationships.

In the complete projection, the latitude lines would be full ellipses, and the

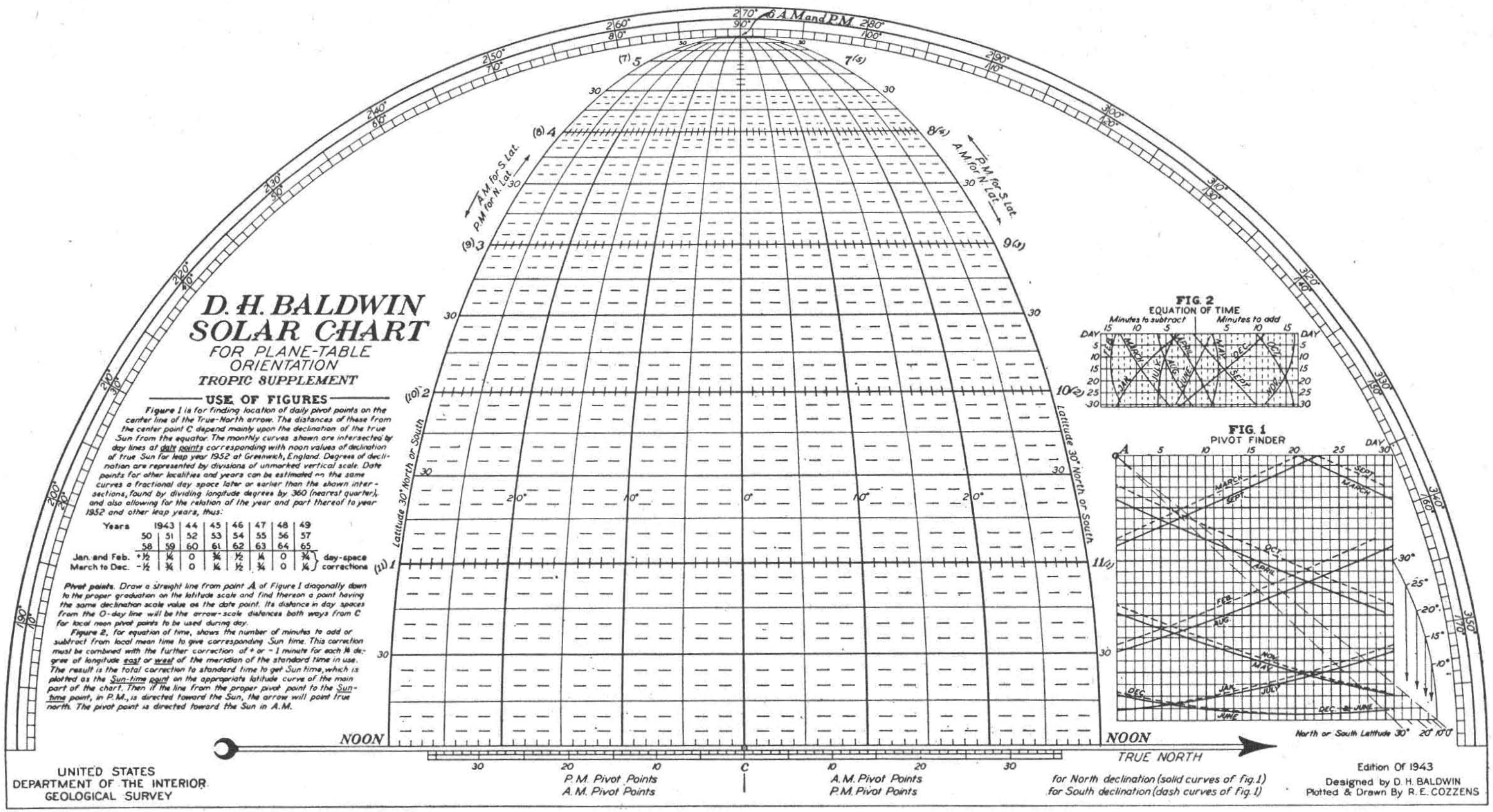

FIG. 3. The Tropic Supplement of the Solar Chart.

chart would be twice as big as it is and symmetrical; but only half of it is required in practice.

By this arrangement, the momentary position of the sun with respect to the station occupied is properly represented by the relative position of the afternoon sun-time point with respect to the P.M. pivot in the hemisphere involved. But the relative positions of sun-time point and pivot point are transposed for morning observations, so that the A.M. pivot point should be directed toward the sun from the sun-time point. The two pivot points, A.M. and P.M., are required each day, because only two quadrants instead of four are used to show the relative position of sun and observer.

The foregoing explanation may help to visualize the working of the chart, although it has been based upon the apparent movements of the sun about the earth rather than the actual motions of the earth about the sun.

The 1943 edition of the original solar chart contains new features providing for its use at latitudes numerically greater than 30° in both Northern and Southern Hemispheres. The Tropic Supplement, made available in 1943, is for use between latitudes 30° north and 30° south.

All the latitude lines shown on the chart apply equally well for either the Northern or the Southern Hemisphere. The main latitude lines are intersected by time lines, the hour graduations being numbered both clockwise and counterclockwise around the chart for use in the Northern or the Southern Hemisphere, respectively.

The following examples are submitted to illustrate the use of Figure 1 of the chart.

Original Chart

For Washington, D. C., latitude 39° north, longitude 77° west on July 30, 1943:

Draw a straight pencil line from point *A* to latitude graduation 39°. Next find the date point on the July curve for July 30 and longitude 77° by advancing $\frac{1}{4}$ day for the longitude interval in degrees from Greenwich compared with 360° to the nearest $\frac{1}{4}$ day, then retreating $\frac{3}{4}$ day for July of the year 1943, as indicated by the table. The true date point for the place and date will then be found on the July curve at the 29.5 day reading. This corresponds to a declination value of 18.6°. The same declination on the diagonal line for latitude 39° falls at day line 21. The pivot points will thus be 21 day-spaces north and south of point *C* upon the center line of the arrow. As the declination is north, the A.M. and P.M. pivot points will be north and south, respectively, of point *C*.

If the latitude were 39° south, off the Coast of Chile, South America, other items remaining the same, the A.M. and P.M. pivot points would be reversed. The morning and afternoon curves would be transposed also, the hourly marking being counterclockwise for the Southern Hemisphere.

In the Southern Hemisphere, the southern polar axis is the one elevated above the horizon plane; but the arrow always points north.

Tropic Supplement

For San Juan, Puerto Rico, latitude 18° 28′ north, longitude 66° 05′ west, on December 4, 1943:

Longitude 66° west, to the nearest quarter, is $\frac{1}{4}$ day west of Greenwich, and the correction for December of the year 1943 is $\frac{3}{4}$ day east, placing the date points $\frac{1}{2}$ day earlier along the December curve than the intersection of the day line. This makes the date point for December 4 fall at the 3.5 day reading, which corresponds to a declination value of 22.2° south. This declination value projected to the diagonal line for latitude 18° 28′ cuts it at 3 day-spaces from the 0-day line. The pivot points on the arrow will therefore be 3 day-spaces north and south of point *C*. The declination being south, the north pivot point is for P.M. and the south one for A.M., to be used with sun-time points along the pencil curve drawn for latitude 18.5°, time designations being clockwise.

A corresponding point in South America for the same latitude south, near Sucre, Bolivia, would necessitate selection on the same curve of time points for south latitude time designations, distinguished by lighter number in parentheses, which run counterclockwise.

When the chart is actually in use some means should be provided to make sure that the edge of the gnomon which casts the sun's shadow on the chart is exactly plumb laterally during the observation, as illustrated by the shadow plane of a plumb line. An attached level and adjusting screw may be adapted to this purpose; it should be mounted so as to prevent the gnomon from having any appreciable slope in a direction transverse to that of the sun. If the gnomon slopes slightly toward or away from the sun no real error will be introduced. The chart should be carefully leveled when in use.

The chart provides a graphic means for orienting a plane table without a compass. It is, therefore, particularly useful for running traverses in regions where local magnetic disturbances exist. Where it is feasible to use chart and compass jointly in running a traverse, the relative directions of true north and mean magnetic north for the locality should be shown either upon the chart or upon the plane-table sheet.

The operator should fasten the chart by scotch tape or other means upon the plane table so that the arrow indicating true north will be parallel to the true meridian for the occupied location as drawn on the plane-table sheet. The chart may be trimmed down to avoid covering too large an area on the plane table. If desired, a short piece of a needle can be substituted for the pencil mark indicating the pivot point. By changing its position at noon to mark the correct pivot point for the day and part thereof, it may then be used as a mechanical stop for the base edge of the gnomon.

As a surveyor becomes familiar with the chart, he may discover other purposes to which it can be adapted.

The North Star usually can be seen with a transit during daylight hours in clear weather, if there is some way to point the telescope very nearly towards it. Transitmen may find the chart useful in making such preliminary pointings because it is graduated for reading the sun's direction in degrees of azimuth. For this purpose the chart need not be mounted or leveled, and a gnomon is not required. The sun's direction, read from the chart, is set on the vernier of the transit, and the sun itself can then be used as a backsight from which to turn the angle to true north or to the calculated azimuth of the North Star.

When rapid reconnaissance surveys are made, using photographs taken from ground stations, the Solar Chart might provide the means to orient the camera with a higher degree of dependability than can be done with a compass.

The chart and the compass may be used together to detect local deflections of the needle, and thus will aid the geologist in the exploration of magnetic deposits.

The Solar Chart may find still other ways in which it may serve the rapidly developing art of photogrammetry.