Chapter 2
Acquiring Data

2.1 Archaeoastronomy Fieldwork

Ancient peoples' attitudes towards, and relationships with, the natural environment and the landscape were often completely at odds from ours. Two fundamental concepts must be borne in mind, in particular. The first is that ancient man was a religious man, and the second is that religion was bound up with the natural cycles, and these natural cycles were bound up with power. We shall gradually gain more insight into these fundamental concepts as this book progresses, but it is essential to take account of them when engaged in fieldwork because they were *reflected in the landscapes.* Typically the monuments which are the object of study of archaeoastronomy are immersed in landscapes which were of special, sacred significance for the people who built them. Therefore, the first step in any kind of archaeoastronomy fieldwork is to look around carefully, trying to understand how the ancient configuration of the surroundings might have been. This might be relatively easy if the environment has remained unspoilt or, on the contrary, depressingly difficult if humans have modified the landscape beyond recognition. Furthermore, we must try to imagine the landscape and the sky as a whole, since it is in this way that ancient people perceived the Cosmos around them. This may also be problematic, due to environmental pollution, light pollution, and—last but not least—precession. Fortunately, as we shall see in the next chapter, computers may be of enormous assistance in tackling these tasks through the use of virtual globes and planetarium software.

The second main point, after seeking to appreciate each site as a whole, is to make an accurate relief of the visible horizon. This has an obvious technical purpose, namely, to allow the calculation of the declinations relating to directions of interest through alt-azimuthal coordinates. In this respect, the role of this relief is fundamental: it may happen, for example, that an azimuth which is many degrees to the south of the azimuth of the rising Sun at the winter solstice with a flat horizon may correspond precisely to the solstice if the horizon itself is occupied by

G. Magli, *Archaeoastronomy*, Undergraduate Lecture Notes in Physics,
DOI 10.1007/978-3-319-22882-2_2

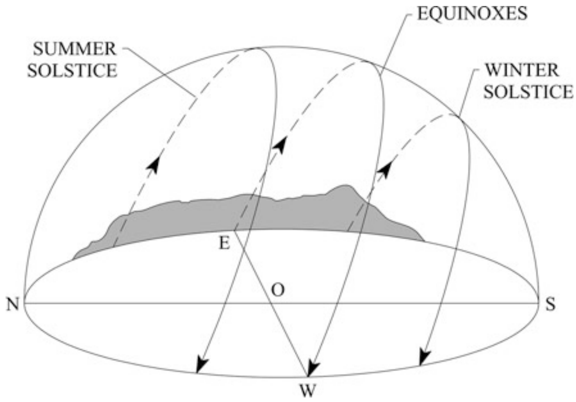

Fig. 2.1 The effect of a non flat horizon on the local observations of the rising sun

mountains high enough to hide the climbing Sun behind them, up to when our star has an altitude—and therefore an azimuth—much greater than those at rising (see the example of Aosta in Sect. 10.3) (Fig. 2.1).

The relief of the horizon is also important for another reason, since prominent features may be of cultural/sociological interest, such as sacred mountains, or special profiles which were considered sacred in ancient times. Additionally, the horizon may be occupied by other monuments that are culturally interrelated, and profiles may display typical breaks (notches or peaks) that might have been used as distant foresights to observe astronomical phenomena.

The third main point is to pay attention to as much detail as possible. Bring an old-fashioned paper notebook, and make sketches of anything that grabs your attention, taking notes as you go along. Bring a digital camera and take pictures from all angles; more generally, try to record all things which might turn out to be significant in the follow-up analysis. Even armed with all this, however, further visits will inevitably be necessary after the first data analysis of a site has been done.

Finally, you are ready for the relief of the possible alignments using the techniques described below. For this relief, whatever instrument you use, the first step is to find north. The second step is to be *sure* you have found north. The third step is to be really, really sure that the direction you have found and you are currently calling "north" is the true north (of course, within the expected range of errors). Now, take as many measurement as possible, repeating them with different means whenever possible. For instance, always have a look at the Google Earth ruler on your PC, even if you are making a high precision on-field relief with a theodolite. Be careful about the significance you attach to a site in terms of alignment. Indeed, if you have a well-preserved Greek or Egyptian temple, then it will be easy to determine the main axis of the temple and this alignment will obviously be the principal one to be measured. But if the monument is in a poor condition, it may not be so easy. Also, in restricted areas it is better to identify ranges rather than single alignments; for instance, if you are measuring a row of a few megaliths, it is not easy—or it may even be impossible—to define a single line of sight which "crosses the centre" of all the stones (Ruggles 1999).

It might be in order here to explain few notions relating to the acquisition of experimental data in physics. It should be said that nothing can be measured with *absolute* precision. First of all, any instrument has an intrinsic limit, beyond which we cannot measure. For instance, if we measure the side of a table with a ruler graduated in centimetres, we can only claim to know its length within ±1 cm. In any measure, one defines *accuracy* as the degree of proximity of the result to the true value of the sought quantity. Accuracy is different from *precision* which is the degree to which repeated measures in the same experimental conditions give close values. A diligent experimenter must do his best to improve both by eliminating sources of error. To understand this, we can use a simple analogy. If I am a good archer, my arrows will all reach the target in a restricted zone (high precision). But if my bow is not perfectly balanced, this zone will not be in the centre of the target (low accuracy). Correspondingly, there are two different sources of errors operating here. One is systematic: it is the fact that the bow is not balanced. The other is random error: on the basis of factors which vary slightly with each bow, even the most skilful archer will not send all the arrows exactly to the same point. Balancing the bow will thus be in order, and making several shots will identify better the area of the target. Analogously, in archaeoastronomy it is always advisable to repeat measurements several times, and to attempt to eliminate all systematic errors.

2.2 The Magnetic Compass

The Earth possesses a magnetic field which effectively makes our planet a huge magnet. The poles of this magnet correspond broadly to the Earth poles, and the force lines of the magnetic field roughly correspond to the meridians. Since the magnetic field is neither constant nor uniform, an iron needle rotating freely on the Earth's surface aligns in a direction—called *magnetic north*—which depends on the position of the observer as well as on time. The deviation of the direction of magnetic north with respect to the geographical north, in a certain place and at the certain time, is called magnetic declination (Fig. 2.2).

A (magnetic) compass is an instrument based on a magnetised pointer turning freely upon a pivot, in air or in a stabilising fluid. When the compass is held level, the needle turns until it stabilises, pointing toward magnetic north. The compass is equipped with a circular grade scale which allows for the determination of azimuths in relation to the magnetic north. For archaeoastronomy, a *bearing* compass—that is, a magnetic compass mounted in such a way that it allows taking the bearings of objects by sighting them with the lubber line interposed—is worth using.

The compass is a very simple, relatively cheap and pocket-sized instrument, which works without any specific preparation, under any atmospheric conditions, and as such it should be an inseparable companion for any archaeoastronomer. It allows us, in particular, to have a first snapshot of the orientations on a site. What is

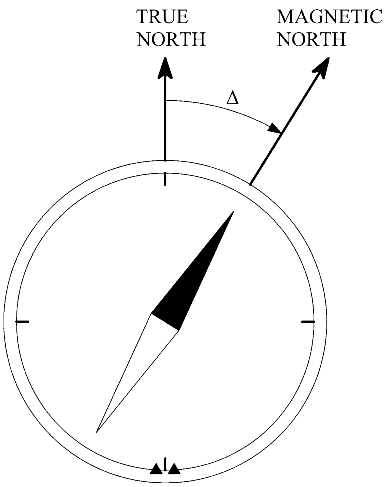

Fig. 2.2 The magnetic declination

more, if used with due caution, it can also be employed for scientific surveys. Caution should be taken with the following:

- as with any instrument of measurement, your compass might have a non-negligible intrinsic error (nothing to do with the error due to magnetic declination, which is addressed below). Check for the presence of an intrinsic error by making a double-blind measure of a trial azimuth with a high accuracy method (such as a theodolite, or using an already well-measured alignment).
- as with any measurement, always repeat the bearings several times and take averages. For instance, if you want to measure the axis of a temple, measure from both extremes; if you are working with a colleague, take four measurements, and so on.
- the compass is sensitive to iron. Iron can be naturally present in the soil and may cause magnetic anomalies, and consequently, wrong readings. Also beware of: iron bars in fencing around archaeological sites, metal bars in restoration scaffolding, iron in the archaeoastronomer's wristwatch or glasses etc. The compass is also sensitive to electromagnetic fields of any nature (which may be generated by electric wires or personal computers). Information about the possible presence of local magnetic anomalies should be obtained, and the utmost care taken to avoid any distorting influences.

Once a set of compass measurements has been carefully obtained, the database must be accurately adjusted for the systematic error due to magnetic declination. Sometimes the value of magnetic declination appears on official maps, together with an estimate of future variations. This kind of information is, however, seldom reliable and in any case *insufficiently accurate* for archaeoastronomy studies. Just do not use it. Fortunately, the National Geophysical Data Center of the National Oceanic and Atmospheric Administration of the United States provides a very efficient free online calculator, which—on the basis of a mathematical model of the

Earth's magnetic field—provides the magnetic declination once geographical coordinates and time have been inserted. Suppose, for example, that the value given for the time the measurements were taken is 4 degrees east. This means that any reading you took indicated an azimuth with a "zero" point 4° greater than the true zero; accordingly, you must add 4° to any measure. If the declination is, say, 5° west, the bearing exceeds the true one so, in other words, you must subtract 5° from any measure.

2.3 The Clinometer

The second set of data required in archaeoastronomy fieldwork is the altitude of the visible horizon in relation to all the azimuths of interest. In archaeoastronomy we are not so concerned with the distance of objects, but rather, we need to know to what extent they occupy the view. In other words, we are interested in angular heights: a hill which is 100 m high but is very near can block the view much more than a distant lofty mountain. To measure such *apparent* heights one needs to measure angles of sights. A clinometer is a simple instrument for measuring such angles, which works—like the compass—under any climatic conditions, and as such is quite adequate for a preliminary and/or quick survey of a site (sometimes compass and clinometer are combined in a tandem instrument) (Fig. 2.3).

Essentially, a clinometer is a goniometer used vertically, and indeed a simple clinometer can be constructed by using a half-goniometer (a graduated semicircle). Fix the base of the semicircle on a stick and let a plumb cord hang freely from the centre of the circumference. Then place the stick in line with the eye and point at (or to be more exact, look through) the edge of the object you want to measure. Then the cord will "cross" the graduated semicircle at a certain value. The apparent altitude in degrees of the sighted object is obtained by subtracting this value from 90°. Professional clinometers employ the same principle, but work with a disc which is able to rotate freely in an oil bath. Standard professional clinometers (such

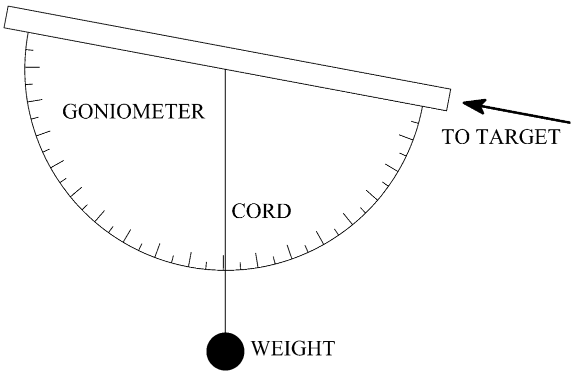

Fig. 2.3 A clinometer is essentially a goniometer used vertically, as shown in this picture

as those which can be purchased combined with professional compasses, like precision compass-clinometer instruments), if used carefully, can attain a precision of ¼°. It goes without saying that it is better to repeat several times also height measurements, recalling however, of course, that they depend on the position from which they were taken. For instance, while you can measure the azimuth of a straight line (like the axis of a temple) from any point along it, the horizon height will be different from point to point.

2.4 The Theodolite

One may often chance to see on roads or in construction sites (and also in archaeological excavations) two people who are working, one with an optical instrument mounted on a tripod, the other with a marked post equipped with a reflection signal. They are performing a survey using a *theodolite*, an optical instrument for measuring angles in horizontal and vertical planes.

A theodolite is essentially a telescope which is turnable both horizontally and vertically, fitted with scales which allow the measurement of both angles relative to the sighted point with a excellent precision, typically better than one arc minute. In today's theodolites, readings are usually electronic, and an integrated electro-optical distance measuring device, generally infrared-based, allows the measurement of distances and thus a 3D mapping. These integrated instruments are called total stations. Data can be registered electronically and downloaded in external devices.

Clearly a theodolite is the most suitable instrument for archaeoastronomical measurements (azimuths and horizon heights) (Aveni 2001). However, it can provide very reliable results only if the data, which a priori refer to the instrument's arbitrary reference system of coordinates, can be related to geographical data, that is —yes—if true north has been ascertained accurately. So, without wishing to state the obvious, it should be reiterated that using a very precise instrument like a total station is useless in archaeoastronomy if the geographical north has not been determined with comparable precision. Since, however, an approximate north usually suffices for standard theodolite uses in civil engineering, it may be the case that even trained theodolite surveyors are not acquainted with the methods used for a precise determination of true north. So I shall briefly describe how to proceed with such a determination (Aveni 2001).

The idea is based on the fact that it is possible to discover with great accuracy the position of the Sun in the sky at any time with the tables called ephemeris, where the Sun's azimuth and altitude are tabulated at any place for any given date and time, or with appropriate computer software. Therefore, by knowing at what instant of time a measurement of the Sun is taken, we immediately know at which azimuth in relation to true north the reading corresponds and, accordingly, set the zero of the instrument. It follows that the theodolite can effectively be used only on days in which at least a good twenty/thirty of minutes of sunshine, most preferably close to noon, are available on the site. Moreover, a radio-chronometer will be needed.

In practice, one first determines an arbitrary zero-scale by measuring the azimuth of a fixed, possibly distant and elevated object (antenna, electric wire, bell tower or the like). All measurements will be taken, with the high precision of which the instrument is usually capable, in relation to this *arbitrary* zero. Once the true azimuth of the reference object is known with respect to north, this value will be used to correct all other measures. To watch the Sun, the instrument must be equipped with a specifically guaranteed sun filter on the lens; looking directly at the Sun any other way is potentially harmful both for the instrument and for the surveyor's eyes. It is always advisable to perform this procedure during the central hours of the day. Indeed, because of refraction, measurements in the first/last hours of the day may be subject to errors. In this respect, it is important to remember that time is conventionally the same on each time zone, but the true time at which the Sun culminates—the local noon—varies within the time zone and depends on the specific latitude. It is, therefore, essential to have a precise determination of the geographical coordinates of the site, which can be obtained through GPS reading (see below). Once everything is ready, the operator centres the Sun in the theodolite viewing grid while watching the chronometer or, even better, while an assistant calls out the time from the chronometer. Successive readings can now be taken and averaged to obtain the azimuth with maximum accuracy.

2.5 The Global Positioning System

The Global Positioning System (GPS) is a free-access navigation system based on a cluster of satellites orbiting the Earth and completing one revolution in 12 h. The satellites (currently 32) are distributed on six different orbital planes. The system has been specifically devised in such a way that on any point of the planet's surface it is, in principle, possible to receive the signals from a number of satellites varying between five and eight. Each satellite transmits continuously two sets of data: time and satellite position at that time. To access the system one needs a GPS receiver. The receiver computes the distance to each satellite. Then, using these distances and a relatively simple algorithm, its software is able to identify the receiver's own position on Earth: latitude, longitude as well as altitude (navigation systems, such as those used in cars, also apply other algorithms, which allow the determination of other parameters like receiver speed and direction of motion). Obviously, the greater the number of satellites the receiver can track, the more accurate the measurement will be.

Several phenomena affect the precise synchronisation between each satellite and the receiver, producing errors in positioning. Of course, in archaeoastronomy we need the greatest possible accuracy, and there are techniques—based on data analysis and/or the use of differential systems correcting the incoming signals by means of data from reference receivers—which enhance the accuracy of standard GPS positioning. Another way to improve accuracy is to use an instrument able to connect both to GPS and to the Russian cluster of satellites GLONASS (which works much in the same way as GPS). The standard error of a normal GPS is a few metres, which can be reduced by up to few centimetres by proper data processing. It should be said that—even when a single economical GPS is used—it is always expedient to try to work with as many satellites as possible (traceability of satellites depends, for instance, on the presence of woods), and to let the instrument, held in a fixed position, acquire data for several minutes.

In considering the application of GPS in archaeoastronomy fieldwork, and thus the measuring of azimuths with the aid of a GPS, two different situations must be distinguished. First of all, consider the case of long distance measures—in the order, say, of several hundreds of metres or more, as might be, for example the straight roads of a Roman town, or a long ceremonial road, such as the "Street of the Dead" in Teotihuacan, Mexico. In such cases, a direct measurement with a GPS is certainly reliable: the instrument can be used to obtain the geographical coordinates of the two extrema of the alignment considered, and preferably also a few readings along the same line. Then simple trigonometry formulas (the so-called Puiseux-Weingarten transformation) can be applied to find the azimuth (Muller 2012).

Obviously, the same procedure can, in theory, also be used for buildings: for example, to measure the axis of a Greek temple. However, the error in measurement increases the shorter the distance is between the extrema, so in such cases the GPS is best applied together with another device. Again we should remember that the main point of any measurement campaign is firstly to find geographic north. To this aim GPS can be used to find the azimuth of a fixed direction (and consequently, north) using the technique described above for long alignments. It is often sufficient to identify a prominent far-off point or landmark—but one that is visible and accessible from the site in question, for example, a water reservoir, or a bell tower—and to GPS-measure this alignment first (the optimal target should be at a distance of several kilometres). The azimuth thus obtained can then be used to calibrate locally another instrument, a theodolite or even a magnetic compass.

To conclude, a few words about the choice of the most suitable instrument are in order. If used correctly, a good compass can give azimuths within ½°, while a theodolite or a differential GPS can give results within $1'$ (or even less, but efforts to reduce errors further would be frankly exaggerate, since a direction originally determined by the naked human eye—and therefore with a resolution of at most $2'$—is being measured). When and where it is advisable to use the first or the second method? The answer is that the magnetic compass is a cheap, handy instrument that can always be used, in any weather conditions and in any situation. This means that it should *always* be used. The problem, rather, is knowing when it will be enough (Belmonte and Hoskin 2002). This would happen in cases where the geometry of the monuments cannot be ascertained with exactness (think for instance of the axis of a partly ruined megalithic tomb) and/or where there are hundreds of monuments to be studied in a limited amount of time (such as dozens of tombs in a necropolis). Equally, if the position of the monument allows a very clear determination of the direction that has to be measured—let us say, the sides of a Greek temple or the main urban axis of a town—then it is certainly wise to use at least one more refined instrument. This is particularly important if there is a strong likelihood that ancient surveyors were working with a very high degree of accuracy, as is the case, for instance, with the Giza pyramids (Sect. 8.1).

2.6 Virtual Globe Software

The use of *Virtual Globe Software* is of enormous assistance both in studying and researching archaeoastronomy. At the moment of writing, the most diffused free software of this kind available is Google Earth, on which I shall concentrate here (another very useful one is World Wind).

A virtual globe is essentially an extremely accurate computer version of a world globe. It maps out the Earth, area by area, by superimposing images obtained mainly from satellite imagery. It also provides 3D reconstructions of buildings and street-view navigation. The resolution is in most cases good and gives a fairly good picture of a site. Obviously, personal visits to sites are fundamental in archaeoastronomical research, but the program can be of great help to a student who wants to study, for instance, the urban layout of a Maya town without being able to fly off to visit it. The use of virtual globes is also recommended in archaeoastronomical research. Indeed, some sites may be inaccessible due to hazardous conditions prevailing locally, such as conflicts. What is more, landscape and visibility at many sites were different in ancient times, and these programs allow us to study visibility lines that are today lost or broken up by intervening obstacles. By way of example, as we shall see in Sect. 8.3, the main axis of the Necropolis of Giza points to the opposite bank of the Nile, towards a place (the Temple of Heliopolis) from which the huge pyramids of the plateau were plainly visible in ancient times. Today, alas, they are irrevocably hidden from sight owing to the encroachment of the buildings of modern Cairo as well as atmospheric pollution.

The tools an archaeoastronomer needs to use in Google Earth are simple:

(1) the *ruler* option, which allows the calculation of distance and azimuth between two fixed points.
(2) the *elevation profile* option which visualises the elevation between the two extrema of a chosen path and thus the projection of the line between the two points previously selected (Figs. 2.4 and 2.5).

The ruler thus gives the azimuth of desired directions: main axes of towns, sides of buildings, and the like. The elevation profile allows us to deduce the horizon height from a fixed observation point. A note of caution: the image shown—which is by default the one most recently acquired by the database—is not always the best one available for the area (for instance, a site might have been covered over for conservation reasons). To check previously archived images use the "show historical images" option.

Fig. 2.4 Selinunte. Satellite view of Temple E, with the Google Earth ruler showing the azimuth of the building (Image courtesy Google Earth, drawing by the author)

Fig. 2.5 Selinunte. Satellite view of Temple E, with the Google Earth ruler showing the azimuth of the building projected for several kilometers up to the hill at the local horizon (see Sect. 10.1 for details on this temple). Altitude profile is shown (Image courtesy Google Earth, drawing by the author)

It is a good idea to treat the program working space as an experimental field: repeat measures, always take them in both directions, and so on. If used correctly, in many cases an instrument as simple as the ruler gives such a good result that it can be used as an additional check of measurements obtained on field. Furthermore, it can be used to geo-rectify maps obtained by conventional means and/or found in old published works; it may frequently happen that such maps are badly oriented (that is, the north shown is not geographic north), not through negligence on the part of the surveyor but because magnetic north was used. A simple procedure allows us to superimpose the scanned image of the map in the program machinery and thus identify true north on the map with a reasonable approximation.

References

Aveni, A.F. (2001) Skywatchers: A Revised and Updated Version of Skywatchers of Ancient Mexico, University of Texas Press, Austin.

Belmonte, J.A, Hoskin, M. (2002) Reflejo del cosmos : atlas arqueoastronómico del Mediterráneo Antiguo, Equipo Sirius, Madrid.

Muller, J. (2012) Geodesy, de Gruyter, London.

Ruggles C.L.N. (1999) Astronomy In Prehistoric Britain And Ireland. New Haven & London: Yale University Press.

Springer

http://www.springer.com/978-3-319-22881-5

Archaeoastronomy
Introduction to the Science of Stars and Stones
Magli, G.
2016, XIII, 246 p. 164 illus., 111 illus. in color., Softcover
ISBN: 978-3-319-22881-5