1.1 Measuring the Motion of Celestial Bodies

The earth rotates around its own axis in approximately 24 hours, and moves on an ellipse, with the sun at one focus, completing a revolution in approximately 365 days. When they are seen by a fixed observer on the surface of the moving earth (the only point of view that concerns us here), then, all heavenly bodies move.

If we extend the plane on which the earth moves around the sun, imagining we are cutting the celestial sphere, we can define a circle known as the *ecliptic*. The earth's axis is not perpendicular to the plane of the ecliptic, but is inclined about 23½ degrees with respect to it. This is thus the angle that the ecliptic forms with the *celestial equator*, that is, with the projection into the sky of the terrestrial equator. The inclination, or *obliquity*, of the ecliptic gives us the alternating seasons and is thus essential for life itself. (Over thousands of years it undergoes only slight variations). For us earthlings the ecliptic also represents the path of the sun in the course of the year in relation to the stars dotted around in the background.

If we imagine prolonging the terrestrial axis onto the celestial sphere, a point in the sky is identified that we call the celestial *pole* (north or south depending on the hemisphere of the observer; but to simplify matters, I shall refer only to the north pole). If we lower the perpendicular to the horizon from this point, geographical north can be determined. Once geographical north is known, two *coordinates*—that is, two numbers—are needed to determine the position of a star in the celestial sphere at any moment, just as longitude and latitude are needed to identify a point on the earth’s surface. There are many *systems*, that is, pairs, of possible coordinates, but two pairs are fundamental. The most intuitive system, hence the one preferred in this book, is based on *azimuth* and *altitude*. Given a point $P$, whose coordinates
Figure A1.1: The path of the sun during the year, viewed by an observer at northern tropical latitude.

Figure A1.2: The north celestial pole

we wish to find, we imagine tracing the vertical plane that passes through this point. This plane intersects the horizon of the observer at point $A$; the **azimuth** is the angle between north and the point $A$ on the horizon, counting positively from north to east, and the **altitude** is the angle measured on the vertical circle from $A$ to $P$ (in particular, the altitude reached by a star when it passes the celestial meridian, that is, the ideal projection of the observer’s meridian into the sky, is called the **culmination**).
The second system of coordinates is easily understood if one imagines measuring the latitude and longitude of a point on the celestial sphere. The angular distance of the point from the celestial equator toward the pole gives the analogue of the latitude and is called the \textit{declination}; the analogue of the longitude is called the \textit{right ascension}, and it is measured from a point (the vernal equinox) along the celestial equator to the “hour circle,” the maximal circle passing through the pole and the point.

1.2 The Sun

The movement we are most familiar with is that of our star, the sun. The sun rises at a certain point on the eastern horizon, varying each day; it makes an arc in the sky and sets at a certain point on the western horizon, varying each day, following a cycle that includes two extrema (also called \textit{standstills}): a maximum one, a northernmost rising point, the \textit{summer solstice}, and a minimum one, a southernmost rising point, the \textit{winter solstice}. At these two rising points, the sun rises only once a year; at all the other points in between it rises \textit{twice} a year. Twice a year the sun crosses the celestial equator and therefore has vanishing declination; these days are termed the \textit{spring equinox} and the \textit{autumn equinox}. The definition of the equinoxes in a \textit{cultural}, therefore archaeoastronomical, context, is extremely delicate, however; see Ruggles (2005) for details. The motion of the rising point throughout the year is sinusoidal, very slow around the solstices and very fast around the equinoxes.

The Tropics are the two parallels, symmetrical with respect to the equator, that mark a belt outside of which the sun never passes to the \textit{zenith}, that is, vertically above an observer’s head at midday. Within the tropical belt, the sun passes to the zenith twice a year, the first after the spring equinox, and the second after the summer solstice; at the Tropics themselves the sun passes to the zenith on the same day as the summer solstice.

If we observe, for instance, the eastern horizon, day after day, from a fixed position, it is possible to identify and mark on the ground the directions in which the sun rises on the days of the zenith passages and the direction of the rising point at the day of the summer solstice. The naked eye is assisted in this type of measurement by “foresighting,” that is, observing the star with an instrument interposed, which might be a finger, a stake, a cross-staff, or a fork. Once markers have been set out on the ground indicating the various directions on the horizon—stones, for instance—the corresponding positions of the sun can be deduced and subsequent positions can be forecast. The measurements will be more accurate if the alignments are long,
and for this reason, to achieve greater precision, it is better to adjust the position of the observer in order to use, for the desired alignment, a marker located on the horizon (for example, a far-off mountain peak or a notch).

1.3 The Moon

The way the observer on earth sees the motion of the moon is quite complicated. The moon rises in the east and sets in the west with a cycle similar to that of the sun over the course of a year, that is, with one extreme located north of east and the other, symmetrical, south of east, a cycle that only lasts 27.2 days, though. So we talk about northern and southern lunar standstills, similar to the two solstices. The lunar phases depend on the fact that an observer on the earth only sees the part of the visible face of the moon that is illuminated by the sun. The cycle of the phases is completed in 29½ days. The ideal plane that contains the earth and the orbit of the moon is inclined by about 5 degrees (5 degrees and 9 arc minutes) compared to the plane of the ecliptic (the two intersection points of the orbit of the moon with the ecliptic are called nodes). This fact has extremely important consequences. Indeed, there would be many eclipses, periods of time when the moon is located between the earth and the sun, obscuring the latter, or the earth is between the sun and the moon, obscuring the latter. On the contrary, since eclipses occur when the three points are aligned, they can

![Diagram showing rising and setting azimuths of the moon at the two standstills compared to those of the sun.](image)

**Figure A1.3:** The rising-setting azimuths of the moon at the two standstills (heavy solid lines) compared with those of the sun.
only take place in the vicinity of one of the nodes. Eclipses thus follow cycles that can be studied, enabling future predictions to be made (see Aveni 2001 for a complete discussion of the subject).

As a result of various factors that would take too long to go into, the node line of the moon revolves clockwise in relation to the moon, completing a cycle every 18.61 years. Thanks to this phenomenon, lunar standstills, unlike their solar counterparts, are subject to an oscillation, whose complete cycle lasts 18.61 years. During this cycle the azimuths of the northern lunar standstills fluctuate between a maximum that is further north than the summer solstice and a minimum that is further south than this, and a symmetrical situation occurs for the southern lunar standstills. Accordingly, we talk about north and south major and minor lunar standstills. A slight effect called wobbling, with a cycle of 173 days, also causes the position of the lunar standstills to oscillate slightly by approximately 9 arc minutes.

1.4 The Planets

The motion of the planets is simple: they move along ellipses of which the sun occupies one of the focuses. This, however, is what an observer from outside the solar system would see. We are on one of the planets, and so what we see of the motion of the others depends on this limited position of ours. The inner planets, that is, those between us and the sun, Mercury and Venus, seem to swing back and forth in the vicinity of the sun. Venus is by far the most brilliant body in the sky after the sun and the moon. The time it

![Figure A1.4: Visibility/invisibility of Venus](image-url)
takes Venus to make a complete revolution around the sun (sidereal period) is 225 days, but clearly the earth also revolves around the sun, so from our viewpoint the planet reappears in the same configuration relatively to the sun after a much longer (synodic) period of 584 days. During each cycle, Venus, which gives the impression of swinging like a pendulum, disappears from sight ("behind" the sun) for about 8 weeks, to then reappear as the Evening Star, visible in the west immediately after sunset; then it disappears from sight ("in front of" the sun), to then reappear as the Morning Star. The motion of the other inner planet, Mercury, is similar to that of Venus.

The motion of the outer planets that are visible to the naked eye, Mars, Jupiter, and Saturn (Uranus is right at the limit of visibility with the naked eye and does not seem to have been observed in antiquity) is characterized by a phenomenon known as retrograde motion. This refers to the fact that from time to time the earth "overtakes" a planet, with the result that the latter seems to go backward in relation to the stars, to then resume its normal path.

As far as the observation of rising and setting on the horizon are concerned, the planets follow a cycle similar to that of the sun, whose
extremes, however—as happens with the moon—vary between two positions, maximum and minimum, both in the north and the south.

1.5 The Stars

Given that we are on the earth and the earth revolves on its axis, we see the stars rotating around the celestial pole (north in the Northern Hemisphere and south in the Southern Hemisphere). The movement of the stars is rigid; that is, the relative distance between the stars remains constant (only a few stars break this rule—Sirius, for example—in that they have a significant proper motion; however, their movement in relation to other stars is in any case extremely slow with respect to the human life span and appreciable only in the course of many millennia). The stars situated sufficiently near the pole never set and are termed circumpolar. The stars sufficiently near the opposite pole to that of the observer never rise, and hence are never visible. The visible portion of the heavenly vault thus depends on the position of the observer. Furthermore, it depends on the day of the year. In fact, on certain days a certain star may only be visible during the hours of sunlight, thus effectively being invisible due to the presence of the sunlight. The heliacal rising of a star takes place on the first day on which it becomes visible again, for a brief moment, rising immediately before the sun on the eastern horizon. Circumpolar stars are visible every day of the year.

Since time immemorial, humans have mentally joined up the bright dots of the stars in order to form stylized patterns or figures, the constellations. All the constellations of the ecliptic taken together are called the Zodiac. The constellations of the ecliptic are those that form a background to the motion of the sun as seen from the earth, and thus the sun “shifts” from one constellation to another in the course of the year.

Many constellations were identified as such in ancient times, times in which there was no distinction between astronomy and astrology; it is a beautiful thing that scientists continue to use a language dating from such far-off times; indeed, the traditional names of the constellations are commonly used in astronomy and are used throughout this book too. But please bear in mind that today's so-called astrology, the kind you find in magazine articles about making predictions, while using the same terminology, has absolutely nothing to do with science and, therefore, with reality.

It is fundamental to emphasize that, generally speaking, different constellations were identified in different places and times. This is partly due to the fact that different constellations can be seen from different
Figure A1.6: The motion of the stars visible from an observer in point $O$.

Figure A1.7: The rising sun as seen from the earth in the “background” of the zodiacal constellations during the year.

...
constellation, separated by a hyphen. Many stars, however, have their own individual names. Thus alpha-Canis Major is Sirius, beta-Ori is Rigel, and so on. The stars are not all equidistant from us. Yet we are unable to appreciate the sheer depth of the heavenly vault and we tend to see the sky as a spherical, two-dimensional surface. The only things we are able to distinguish clearly are varying degrees of brightness, and there are a few dozen exceptionally bright stars. The most brilliant by far is Sirius, followed by alpha-carinae (Canopus), alpha-centauri, alpha-bootes (Arcturus), alpha-lyrae (Vega), and alpha-aurigae (Capella).

The practical problems one faces in carrying out precise observations of the sky with the naked eye are beyond the scope of this appendix. I shall merely say that there are a number of factors (apart from the more mundane atmospheric and light pollution), such as parallax and atmospheric refraction, that affect the results of measurements and must be taken into account.

1.6 The Milky Way

The sun belongs to a very common category of star—the “main sequence”—and there exist billions and billions of very similar stars. Stars are grouped into galaxies, systems usually extremely “squashed,” in the shape of a disk, made up of billions of stars rotating around a central nucleus. The sun is no exception to the rule, and is situated at a certain point of one of these disks. We who dwell on an insignificant planet orbiting around an insignificant star belonging to an insignificant galaxy—call it the Milky Way. Because we are inside it, and because it is shaped like a disk, we see it as narrow band of diffused luminosity traversing the sky. Since its luminosity is diffuse, the Milky Way is not clearly visible when pollution or artificial light is present, whereas its presence becomes quite striking and spectacular if the night sky is clear and we are viewing it from a very dark area.

1.7 The Precessional Motion of the Earth’s Axis

All the heavenly phenomena I have mentioned so far can be appreciated from one day to the next, or at least within timeframes of months (for example, the sun moves between the two solstices in 6 months), years (for example, the cycle of Venus), or at most a few dozen years (for example, the
cycle of lunar standstills). There is, however, another phenomenon that evolves over times that are much longer than the average human life: precession.

The earth, like all rigid bodies, is subject to three rotational movements. The first is the revolution around its axis in 24 hours. The earth's axis, however, rotates around the perpendicular to the ecliptic, completing a revolution every 25,776 years, and it also undergoes a slight "swing." These two movements are known as precession and nutation, respectively. The effects of nutation are negligible for the purposes of archaeoastronomy, while knowledge of precession is essential for reconstructing the skies as ancient peoples saw them. To visualize the precessional motion of the earth, the easiest way is to arm oneself with a spinning top (preferably a real one, or else a simulation program on a PC), place one end on the floor, and watch its movement after spinning it and leaving it with a certain inclination with respect to the vertical. It can be seen that the axis of the top, just like the earth's axis, begins to circle around the vertical while the top spins around the axis.

Precession has a significant effect on the observation of heavenly bodies, an effect that is extremely slow in terms of the human life span, though. First, the North Pole shifts against the background of the stars. In fact the North Pole is none other than the ideal intersection between the prolongation of the earth's axis and the heavenly sphere. Since the axis describes a cone, the pole describes what we see (or rather would see, if the change were not so slow as to be almost imperceptible) as a circumference (not quite closed in reality, owing to certain perturbations, which I shall not go into). It should be stressed that it is not the background of stars that move, but the polar axis that points to different regions of the sky; what we call the Pole Star, for instance, is the star that the heavenly north pole is near today.

Just as the North Pole shifts, so too does the South Pole, and this results in some constellations being, at certain times, completely invisible from a certain latitude (because they are too far south) and then becoming visible again with the passing of time. It is evident at this point that precession also has an effect on the apparent motion of all the other stars, which vary, in particular, in terms of azimuth of the rising point and altitude at the meridian. On the other hand, precession has no effect on the apparent motion of the sun and, in particular, on its solstitial points, which are only subject to a small displacement (appreciable over thousands of years) due to the slight variation that the plane of the ecliptic is subject to.

The effect of precession on the zodiacal constellations, that is, the constellations that the sun has "as a backdrop," can be visualized as a slow rotation of the backdrop itself; since there are 12 zodiacal constellations, if
the sun rises against ("in") a particular constellation on a particular day of the year, after about 2200 years (25,776 years of precessional cycle divided by 12, the number of zodiacal constellations, gives 2148 years), it will rise on the same day in the background of the constellation located to the left of the original one. In particular, the constellation against the background of which the sun rises at the vernal equinox defines what is usually called a "zodiacal age" (currently we are at the end of the Age of Pisces and passing into the Age of Aquarius). Once again, however, I stress that we are speaking here of a well-defined, very slow but observable physical phenomenon using a traditional terminology; curiously, the so-called signs of the zodiac used in horoscopes, which (according to modern astrologers) should enable our destinies to be forecast, are actually well out-of-date, exactly because of precession.

Figure A1.8: The path of the north pole with respect to the stars, due to the precessional cycle
Figure A1.9/10/11: The position of the north celestial pole with respect to the stars in 2500 BC (there is a “pole star”, Thuban); in the Roman times (no pole star), today (there is again a pole star, Polaris)

1.8 Making Measures in Archaeoastronomy Fieldwork

To make any kind of measure in archaeoastronomy, it is in principle advisable always to use a surveyor transit, which enables measuring azimuths and the corresponding altitudes at the horizon with an optimal accuracy (within 1 arc minute or less). There are times when the accuracy required in archaeoastronomical studies must be very high, such as when ancient monuments were oriented with astonishing accuracy, for example, the pyramids of Giza, or when they exhibit perfectly conserved and measurable architectural features, as with many Greek temples (for the practical use of the transit in archaeoastronomy, see Aveni 2001). However, in many situations the careful use of a very simple, hand-held instrument, such as a combined clinometer (to measure altitudes) and magnetic compass, may suffice (for further discussion, see Belmonte and Hoskin 2002, Hoskin 2001). To use the magnetic compass properly, it is important to remember that the earth acts like a magnet. Therefore, an iron needle rotating freely on the earth’s surface points toward the poles of this magnet,
in a direction called *magnetic north*. While geographical north (sometimes called true north in this context) is defined invariably by the projection of the earth’s axis into the sky, magnetic north depends on a number of factors, and although it may chance to coincide with true north, it generally varies according to the place one is in, as well as the time. The magnetic compass, therefore, gives an indication of the direction north, which has to be corrected by using (readily available) *magnetic declination* values; further, *magnetic anomalies*, which are special geological features of the site (or the presence of modern iron gates in temples) have to be taken into account.
Appendix 2: Moving Large Stone Blocks in Ancient Times

In ancient times, the most colossal, bulkiest stone blocks imaginable were excavated, transported, carved, and then laid in place. The sight of these gigantic megaliths astounded visitors in the past, and even today one cannot but be dumbfounded by feats that seem to stretch human ability to, if not beyond, the limit. Up to now, however, insufficient research, and particularly fieldwork, has been carried out on the methods employed. The situation is further complicated by the fact that ancient peoples have handed down very little information on their techniques; and besides, such information as we have has often been interpreted wrongly.

The classic, much quoted, example is the fresco found in the tomb of Djehutihotep in Bercia, Egypt. Djehutihotep, who lived in c. 1900 BC, commissioned a huge statue, in sitting position, and the fresco symbolizes its transport. If we trust the artist who painted the scene and assume that the statue and the men dragging it are represented on the same scale, then the statue must have been about 7 meters tall and weighed 70 tons (if the material was limestone; if it was hard stone, then the weight could have been much greater). The monolith is being dragged along on a sled by 172 people, while an assistant is pouring a liquid, possibly oil, in front of the sled to reduce friction, I believe, although some authors have suggested that a ceremonial act was taking place (Heizer 1990). In any case, with or without the oil, it is obvious that 172 people cannot pull a weight of 70 tons, and I also think that this was obvious to the artist depicting the scene, who was simply “filling up space” with groups of people dragging to give the idea that there were many of them, as did the artist who painted the battle scene at Kadesh found in the temple of Rameses II at Abu Simbel, where the pharaoh is seen fighting against a lot of enemy chariots. The difference is that, while nobody would try calculating the number of Hittite chariots deployed in the battle of Kadesh by counting them one by one in Rameses II’s frescoes, many authors have stated that the Bercia painting demonstrates how easy it was for less than 200 men to move 70 tons of statue . . .

To start with I think it advisable to divide the problem of transporting and
erecting huge masses with human labor (though the whole scenario could easily be readjusted to fit animal traction) into three distinct categories, depending on the weight involved.

The first category—standard problems—would cover weights of up to 10–15 tons. Here we are dealing with what would be standard work for well-trained, motivated, and skilled teams of laborers. This category would include the majority of the blocks for the pyramids of Giza; the stones used by the Incas in square-block walls; the Easter Island “standard” statues (about 12 tons); the granite slabs used for the temples at Giza (up to 15 tons); almost all the megaliths of Mycenae, Hittite, and central Italy polygonal walls; and the stones used in the great monuments of Minorca and Malta.

The second category—large problems—would include loads of up to about 90 tons. Falling into this category would be the Sarsen stones of Stonehenge, the granite slabs covering the relieving chambers of the Great Pyramid, many blocks making up the Sacsahuaman at Cusco, and the architraves of the Mycenaean tombs.

The third category—mega problems—covers loads of between 100 and 400 tons. This would include the Great Menhir and other megaliths of Carnac (350 tons), the limestone blocks used in the Khafre and Menkaure temples (up to 250 tons each), many Egyptian obelisks of the New Kingdom (between 200 and 400 tons), and several dozen blocks used in Sacsahuaman (300 tons).

There are, finally, a very few instances in which even heavier loads were transported: these include the so-called Colossi of Memnon (giant statues of the pharaoh Amenhotep III at Luxor, near the Valley of the Kings, weighing up to around 600 tons), and some of the blocks used in building the Temple of Baalbeck in the Lebanon (believed to have been built by the Romans or possibly the Phoenicians) of similar weight.
Before proceeding, it might be sensible to try to get an idea of the modern scale involved here. An average-sized car weighs about a ton. A giraffe crane (the ones you often see in city building sites) can lift up to 15 tons, though not without difficulty. For loads of up to 90 tons, massive self-propelled telescopic cranes are used—a relatively common sight. Greater loads, however, are usually only lifted by overhead-traveling cranes (commonly yellow in color), the type often seen in the docks. Normal giraffe cranes need counterweights and self-propelled cranes need to be heavily weighted at their bases. But overhead-traveling cranes (whose load is basically “hung” from a moving girder) exploit the resistance of the girder. It follows then that this type of load is usually moved on fixed paths fitted with rails (for example, between two areas of a steelworks, or between pier and freighter). A famous example of such cranes is the pair called Samson and Goliath, in a dock in Belfast, Northern Ireland. Each crane can lift loads of up to 840 tons; thus, they would certainly be capable—but only just—of moving Memnon’s Colossi for a few hundred meters.

Moving one-off extra-large loads a distance is, even today, a tricky matter that strong financial or social reasons would have to justify. A recent example of a case where the transport of an outsized load of this kind came close to failure is the Italian submarine Toti, weighing 450 tons, 46 meters long, and 4.75 meters wide. The submarine, after finishing active service in 1999, was towed by river to Cremona without any mishaps. It was then supposed to proceed by land to Milan, where it was to be displayed in the Science and Technology Museum, situated in the city center (the decision to
display an instrument of war in a science museum which welcomes very young children was in itself questionable in my view, though fortunately the submarine, built in the 1950s, was never involved in any kind of combat). After long deliberation, it was decided to drop the costly Herculean task of moving the monster as it was, since there was also the risk that the road would give way under the massive weight, and so the Toti ended its career somewhat ingloriously in Milan’s sewers. To transport the huge object to the final destination, the Milan City Council decided it was necessary to perform some plastic surgery, removing over 100 tons of ballast and other weight and sawing through the conning tower to remove it and make the monster more manageable. Finally, stripped of its splendor and mounted on a specially designed truck, the Toti crossed the city miraculously, with an articulated truck in the rear guard mournfully carrying the sawn-off conning tower and with the backup of a steel gantry crane belonging to the military engineers, just in case.

Let us now try to gain more of an insight into the problem by looking at the force $F$ that is necessary to apply to a load of weight $P$ to drag it up a ramp with friction coefficient $\mu$ and inclination $\alpha$. By doing a simple calculation of elementary physics, this formula comes out as $F = P(\mu \cos \alpha + \sin \alpha)$. In practice, however, the angles of inclination of the ramp are always very small and hence $\cos \alpha$ can be taken equal to one and $\sin \alpha$ approximately equal to $\alpha$. Assuming that a man can move $T$ kilograms, and letting $F = NT$, we can obtain the required number of men with the final formula $N = (P/T)(\mu + \alpha)$. Thus the number of men is directly proportional to the weight to be moved and to the sum of $\mu$ and $\alpha$, which one needs to make as small as possible. To make it clearer with an example, if we assume that a man can move $T = 30$ kg (it should be remembered that it is not like lifting a weight just for a moment as one does in a gym, so this is a reasonable estimate) and that a method is used that reduces friction to a minimum (by pouring oil on the ramp, for example), estimating the friction coefficient to be $1/5$, we obtain for transport on flat ground: $N = P/150$ ($P$ in kilograms). So it takes less than 20 men to move a block of $2\frac{1}{2}$ tons ($2500$ kg), that is, one of the two million standard blocks used in the Great Pyramid (quite a reasonable result that shows that to solve a “category 1” problem of, say, 15 tons, about 100 men were required on flat ground). We have to add all those who did ancillary work, such as checking the smooth running of the sleds, keeping the teams in rhythm, feeding and watering the workers, and so on. Any time it was necessary to cross an irregular terrain, the number of men pulling would have to be increased substantially (for example, on a ramp with a gradient of $1/10$ we would obtain approximately $N = P/100$).

When the weight to be moved begins to increase appreciably, normally
the size of the object in question will also increase, as will problems of finding sufficiently resistant ropes—to say nothing of the logistics of coordinating a large number of men and making enough space for pulling the object. Yet I believe that as long as the weight is kept below a certain threshold (which might be reckoned to be in the region of 80 to 100 tons), we can assume that the degree of difficulty is still proportional to the load being shifted. In other words, it is quite reasonable to suppose that our formula is still fully valid. For example, to pull one of the Stonehenge Sarsen stones weighing 50 tons, we would require about 330 men, which sounds quite plausible.

The laws of physics are indifferent to the problems of mere mortals, and hence our formula continues to be valid, in principle, for any load to be moved. If we wish to move a 300-ton block, we would need at least 2000 men. But it is not quite so simple. In fact, even if the formula says 2000 men pulling together would move the block, it does not say how to arrange a sufficient number of ropes for tugging, or how to get everyone to pull at the same time, and it takes for granted that you have enough physical space for performing the maneuver and that the block will go where you want it to rather than where it wants to.

Even with more moderate loads, a larger number of men would be needed than those predicted by the formula. For instance, we have ethnological reports on the erection of some small monoliths on the island of Sumba, Indonesia, where megalithic monuments are still being put up today, which confirm this fact. These accounts show that a whole village contributes to the erection of a monolith, with hundreds of men working together at the same time, each with his own task to carry out (families save up for years to be able to sponsor the creation of a monument in honor of a dead relative). I tend to think, therefore, that the difficulties involved in transporting excessive loads are much greater than they might appear on paper, and so I must disagree with Robert Heizer (1990), one of the acknowledged experts in the field, who stated: “If a man can complete, with the help of simple tools and techniques, a quantity $X$ of work per day, then 100 men can complete a quantity of work equivalent to 100 $X$”.

To summarize, I believe it is impossible to come up with a magic formula to explain how enormously complex technical difficulties were solved in the past. The only way of really understanding it is to study each problem individually, as indeed is the case today when faced with projects of exceptional difficulty.

Interesting hints might come from those transportation and construction problems that the ancients did not solve. Think, for example, of the unfinished Moai on Easter Island, or the unfinished obelisk, an enormous
monolith that cracked during the excavation stage and was abandoned in a quarry at Aswan, or the most massive monolith ever shaped by men, a block some 30 meters long weighing more than 1100 metric tons, which lies in the stone quarry of the Baalbeck temples. In other cases, however, as we have seen, the puzzle has been solved. The simplest case to consider might be that of the great Egyptian obelisks, for example, that of Thutmose III, today standing in Rome, in Piazza S. Giovanni in Laterano, which weighs approximately 420 tons.

Obelisks were excavated in wide areas in the open air on the banks of the Nile. They were hewn out of the rock by immensely patient stonecutters, who used stone hammers for this long, drawn-out work (they may also have employed wooden wedges, inserted under the blocks and then dampened with water to make them expand, though the use of this technique has been documented with certainty only in Roman times), and then dragged onto huge barges. When the Nile flood level rose sufficiently, the barges floated up and their journey could begin. With this technique, which ingeniously exploited the river and the force of gravity, the Egyptians probably managed to move not just obelisks, but also enormous blocks, such as those required for the Colossi of Memnon.

Another important example is that of the Incas. Thanks to important studies by J. Pierre Protzen (1985, 1993), we have fairly good knowledge of

Figure A2.3: The Colossi of Memnon
the techniques adopted by Incan workers when megalithic blocks of
standard weight (up to 10–15 tons) were quarried and moved. Protzen
successfully performed some experimental tests showing how the blocks
could be carved until they fitted together perfectly, using stone hammers of
various sizes. But we cannot automatically attribute the same techniques and
the same solutions to the construction of the gigantic Incan walls, such as
those in Sacsahuaman, in Cusco, since no modern experimental testing has
ever been done with even remotely comparable weights. For instance, it is
quite difficult to imagine that blocks weighing up to 300 tons could be lifted
and lowered the innumerable times that would have been necessary to
obtain the perfect Incan joints.

It is to be hoped that in the future a systematic analysis on the extraction
and erection techniques used in the past, specifically in erecting the great
megaliths, will be carried out. Any such analysis will only be successful, I
believe, if as much consideration is accorded to the human aspect as to the
technical aspect, using, therefore, the same approach to the past that is
typical of the scientific discipline we have been dealing with in this book.


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