Atlas of historical eclipse maps

EAST ASIA 1500 BC – AD 1900

Translation of cover text

Part of a page from the Astronomical Treatise of the *Chiu-t'ang-shu* ('Old History of the T'ang Dynasty'). Among the astronomical records of various kinds from around AD 760 is the following detailed account of a total solar eclipse:

'2nd year (of the Shang-yuan reign period), 7th month, day *kuei-wei*, the first day of the month. The Sun was eclipsed; the great stars were all seen. The Astronomer Royal, Ch'u T'an, reported [to the Emperor], "On *kuei-wei* day the Sun was eclipsed. 6 *k'o* after the hour of *ch'en* (8.12 a.m.) the eclipse began. It was total at 1 *k'o* after the hour of *szŭ* (9.12 a.m.). The Sun was fully seen 1 *k'o* before the hour of *wu* (10.48 a.m.). The eclipse was 4 degrees in *Chang* (lunar mansion). This represents Chou (state). The *Chin-tê* says that when the Sun is eclipsed between (the hours) *szŭ* and *wu*, this represents Chou. Now Chou is Ho-nan, which is occupied by Shih Szu-ming and his rebels. The *I-szu-chan* says that under a solar eclipse the kingdom will be ruined".'

The recorded date of this eclipse corresponds to AD 761 August 5 and it can be seen from the computer-drawn map that on this day there was a total eclipse visible at Ch'ang-an, the capital of China at the time. The recorded times are only approximately correct but they agree quite well with calculation.

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EAST ASIA
1500 BC – AD 1900

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To Ellen and Penny

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Introduction

Of the various kinds of astronomical phenomena recorded in history, eclipses have possibly the greatest interest and importance in present day research. Not only do they have considerable value in chronological studies, they have also contributed much to our understanding of changes in the Earth's rate of rotation, a major geophysical problem.

The astronomers of China have bequeathed to us the longest and most substantial series of eclipse observations from anywhere in the world. Before about 700 BC the extant records are very sporadic, but since that date roughly one thousand solar eclipses and several hundred lunar eclipses are preserved. The detailed histories of Korea and Japan, both cultural satellites of China, do not commence until much later – towards the end of the 1st millennium AD. However, from then on there are extensive lists of independent eclipse observations from both countries, in addition to those from China. For reasons given below, the present work is concerned only with *solar* eclipses and covers the period from 1500 BC (several centuries before the earliest known eclipse records in China) down to the end of last century.

We have restricted our attention to solar eclipses for two main reasons – historical and purely practical.

Although there are several extant references to lunar obscurations from the earliest historical period in China, the Shang Dynasty c. 1550 to 1045 BC (Keightley, 1978), at all subsequent periods down to the Sui Dynasty (AD 589–616) there are virtually no further records of these events. During this long interval, only solar eclipses were regarded as significant astrological omens and thus worthwhile reporting.

In studying historical eclipses, maps are very useful for representing solar eclipses since the local circumstances vary considerably from place to place. On account of both the lunar orbital motion and the terrestrial rotation, when the Moon passes in front of the Sun the lunar shadow sweeps across the Earth's surface in a few hours. The umbral shadow forms a narrow band, usually more than 10000 km in length but seldom more than 250 km wide. Within this band the eclipse may be described as central since the Moon covers the Sun more or less directly. For a considerable distance on either side of this zone a partial eclipse is visible. On the contrary, in the case of a lunar obscuration, mapping serves little purpose for the proportion of the Moon's disc in shadow is virtually independent of the observer's location; at any instant the appearance is much the same from the entire hemisphere of the Earth where the Moon is above the horizon. Brief tables such as those published by Oppolzer (1887) are thus quite satisfactory for investigating most records of these phenomena.

Central solar eclipses may be divided into three categories; total, annular, and 'annular-total'. A total obscuration, in which the Moon completely covers the Sun for a few brief minutes, producing a deep darkness with the appearance of stars, is certainly the most awe-inspiring. However, if the Moon is in the more distant part of its elliptical orbit when it passes in front of the Sun, an annular or ring eclipse is formed instead; here the diminution of light may be quite small. Very rarely, an eclipse may be annular near the sunrise and sunset position. Under such circumstances, the eclipse track is extremely narrow and over part of its extent the Sun is momentarily

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reduced to a broken ring of light. In this Atlas, all tracks of central eclipses crossing the Far East between 1500 BC and AD 1900 are mapped in detail, making use of recent extensive studies of the lunar motion and changes in the Earth's rotation in the past.

1. Calendar dates

All eclipse dates in this work are expressed in terms of either the Julian or Gregorian calendars, the transition date being AD 1582 Oct 5/15. On the BC/AD system there is, of course no year zero, 1 BC being immediately followed by AD 1. Hence in specifying years of eclipses before the Christian Era we have used negative numbers, equating the year 0 with 1 BC, −1 with 2 BC, etc. Thus the year of the earliest eclipse charted in this Atlas (−1496) corresponds to 1497 BC. This system is followed by Oppolzer (1887) and is in common use in astronomical practice. A number of other dates such as reference epochs are given in this introduction; for these we have adopted the BC/AD system since negative numbers could possibly be mistakenly interpreted as relating to quantities other than dates.

The calendar date which we assign to any particular eclipse is the local date and is independent of the Greenwich meridian. In the region covered by the maps, all places where a particular eclipse is visible share the same calendar date. This date will frequently be one day in advance of the Greenwich civil date (e.g. as listed by Oppolzer, 1887) since the selected range of longitude is far to the east of Greenwich. Eclipse dates as given here should be identical with the corresponding historical date as converted to the Western calendar, useful conversion tables being those of Hsüeh and Ou-yang (1956).

Following the calendar date of each eclipse we have given the Julian day number at the time of conjunction; this is rounded to the nearest integer. Julian *ephemeris* days, beginning at 12h ET (ephemeris time), are used here. The quoted day number thus may exceed by unity the appropriate value given by Oppolzer (1887), which is based on UT (universal time).

2. Fluctuations in the Earth's rotation and the accuracy of the eclipse maps

If the Earth's rate of rotation and the mean lunar motion were uniform, it would be possible to calculate with high accuracy the geographical co-ordinates of the zones of totality or annularity across the Earth's surface for eclipses at any time in the past (or future). In practice this is not the case, mainly on account of the tides produced by the Moon and Sun. During the course of a century, tidal friction in the oceans and – to a lesser extent – in the solid body of the Earth causes a simultaneous lengthening of the day by some 2.5 milliseconds (ms) and a recession of the Moon from the earth by some 3.5 metres. As the Moon's orbit expands in this way, its mean motion slows down (in accordance with Kepler's third law). The equivalent orbital acceleration is approximately −25 arcsec/century^2 ($''/cy^2$), producing a substantial drift in the lunar position over a period of a few millenia. A detailed discussion of the problem is given by Stephenson and Morrison (1984), to which the interested reader is referred. Unless otherwise indicated, the results given in this section are taken from this paper.

In all calculations of the Moon's position we have used the lunar ephemeris j=2 (IAU, 1968), but with a revised value for the lunar acceleration ($\dot{n}$). We have adopted a figure for $\dot{n}$ of −26 $''/cy^2$, as deduced by Morrison and Ward (1975) from transits of Mercury observed over the last 250 years. This result is very similar to that determined from lunar laser ranging by Dickey and Williams (1982), i.e −25.1 ± 1.2. Over the period covered by this Atlas it is unlikely that tidal friction has changed significantly and we have thus assumed a constant $\dot{n}$ throughout. The ephemeris j=2 is based on a value for $\dot{n}$ of −22.44 $''/cy^2$. In order to fully incorporate our choice of $\dot{n}$ we have applied the following additions to the mean lunar longitude (L) of the ephemeris:

$$\triangle L = -1''.54 + 2''.33\,T - 1''.78\,T^2 \qquad (1)$$

Here T is measured in centuries from the epoch 1900.0.

Allowance for variations in the rate of rotation of the Earth is more complex, since

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both tidal and non-tidal changes are present. On the basis of conservation of angular momentum in the Earth-Moon system, the rate of lengthening of the day due to the combined effect of the lunar and solar tides may be calculated fairly accurately for a given value of the lunar acceleration. With $\dot{n} = -26$ "/cy^2, the result is 2.4 ms/cy. Although this may seem very small, the resultant accumulated clock drift (ΔT) over the historical period is large; in T Julian centuries (each of 36525 days) it amounts to some 44 T^2 seconds. Hence by the beginning of the period covered by this Atlas (1500 BC) the tidal contribution to ΔT is roughly 0.5 day. Neglect of this would place eclipse tracks on the opposite side of the Earth from where they would otherwise be. The importance of carefully allowing for changes in the Earth's rotation when investigating past records of eclipses is thus obvious.

Both precise modern measurements and relatively crude pre-telescope observations (mainly of occultations and eclipses) reveal significant non-tidal fluctuations in the Earth's rotation which materially affect ΔT. Irregular short-term changes, the so-called 'decade fluctuations', which can be accurately mapped over the last two centuries, are usually attributed to electromagnetic coupling between the core and mantle of the Earth. These produce deviations from the tidal ΔT parabola by up to 30 seconds of time. Pre-telescopic observations are much too inaccurate to reveal the decade fluctuations but they do provide clear evidence of significant non-tidal changes which are variable on the time-scale of millennia. Possible causes are (i) long-term electromagnetic coupling, (ii) redistribution of material in the interior of the Earth and (iii) global sea-level changes. Analysis of Babylonian observations (mean epoch around 400 BC) reveals that these non-tidal effects reduce the expected (tidal) value of ΔT by more than an hour in ancient times.

Above each map, beside the date, we have given the estimated value of ΔT, based on a detailed investigation of (i) telescopic timings of occultations of stars by the Moon; (ii) medieval timings of lunar and solar eclipses by Arab astronomers; (iii) medieval and ancient sightings of total solar eclipses observed mainly in Europe and China; and (iv) ancient timings of lunar eclipses by Babylonian astronomers. This analysis is based on the same value for $\dot{n}$ as adopted here (i.e. -26 "/cy^2). Our main source of reference is again Stephenson and Morrison (1984). It should be noted that the pre-telescopic values of ΔT are actually calculated on the basis of a preliminary study, the results of which differ only slightly from those of the main paper.

Between AD 1600 and 1900, we have deduced ΔT values from the data at yearly and 5-yearly intervals published by Stephenson and Morrison (1984). Before AD 1600, the following parabolic expressions were used instead, AD 948 being the mean epoch of the Arabian timings mentioned above.

(i) from AD 948 to 1600,

$$\Delta T = 22.5\, t^2 \text{ sec} \qquad (2)$$

(ii) at any time before AD 948,

$$\Delta T = 1830 - 405E + 46.5E^2 \text{ sec} \qquad (3)$$

Here, t is measured in centuries from AD 1850 and E in centuries from AD 948.

The value of ΔT exceeds 1 minute during the whole of the period before AD 1640. Over this entire range of time we have rounded the individual values to the nearest 0.1 minute; later we have gradually increased the quoted precision. Some remarks are necessary on the real accuracy with which ΔT can be determined in the past since this has important bearing on the reliability of the maps and tables.

Reasonable estimates of the uncertainty in the adopted values of ΔT at century intervals back to AD 1600 are as follows: AD 1900, 0.1 sec; 1800, 1 sec; 1700, 5 sec; 1600, 30 sec. Because of the sporadic nature of the pre-telescopic data it would be impractical to quote values at similar intervals before AD 1600. However in the medieval period the uncertainty is not much more than a minute and even well into ancient times the value of ΔT is probably known to within a very few minutes. Thus the groups of Arabian and Babylonian timings give results for ΔT with standard errors of 1 min 20 seconds at AD 948 and approximately 7 minutes at 390 BC. Possibly a realistic estimate of the uncertainty in ΔT by 1500 BC is around 15 minutes. Obviously these latter estimates are much larger than the appropriate rounding errors (0.1 min). However, for purposes of reference we have felt it advisable to indicate the precise value of ΔT used in computing the data for each map.

With regard to the reliability of the eclipse maps and tabular data, the following remarks seem especially relevant. Uncertainties in ΔT are directly reflected in the computed local times of maximum eclipse. However, as the latter are rounded to the nearest minute, errors only become significant in the more ancient past. In practice, as eclipse times are seldom recorded in Chinese history before about AD 1500 – and then only to the nearest double hour – the calculated times may be regarded as of more than adequate precision. A detailed knowledge of the accuracy of the map tracks only becomes important when an observation alleges a very large eclipse. However, such records deserve special attention since they are of value in refining ΔT. In calculating geographical co-ordinates, we have regarded longitude as the independent variable, deducing the latitudes of the edges of the belts of totality for discrete values of longitude. Uncertainties in ΔT produce errors in these latitude limits at each selected longitude. These errors depend also on the angle which a particular track makes with the equator at the appropriate longitude. Thus if a track of totality or annularity runs nearly parallel to the equator at some point, even quite a large uncertainty in ΔT will have negligible component in latitude. For other angles of inclination (I) to the equator, it is readily seen that the appropriate latitude error is approximately proportional to tan I. The Earth turns through 0.25 deg in 1 minute of time. Hence if we let M minutes be the estimated uncertainty in ΔT on a particular date, the corresponding error in the latitude limits is roughly (M tan I)/4. On a typical eclipse map, the mean value of I is some 25 deg (tangent close to 0.5). Thus around the epochs AD 1600, AD 1000 and 500 BC, likely latitude errors at any given longitude are respectively 0.06, 0.15 and 0.8 deg. Even this last amount represents only about 2 mm on the scale of the maps so that the mapping accuracy is expected to be high, even in ancient times.

On the question of investigating hitherto unused records of large solar eclipses from the Far East to deduce ΔT more accurately, possibly the best prospects would seem to relate to the more ancient observations; the material since about 200 BC has been extensively studied. At present, only three records of total solar eclipses are known before 200 BC, all from the chronicle of a single small state – Lu, the home of Confucius. The dates of these events as recorded in the *Ch'un-ch'iu* are as follows: 709, 601 and 549 BC. If any additional observations from the Shang or Chou Dynasties were to come to light they might revolutionise present knowledge of the history of ΔT. It is hoped that the production of this Atlas will encourage research in this field.

3. Capital cities of China, Korea and Japan

(i) China

On each of the eclipse maps we have marked, for reference, the site of a major Chinese city – usually the capital of the time (the Wade-Giles system is used in the transliteration of names). Throughout much of the long history of China, because of the great importance attached to political astrology, the hub of astronomical activity was the metropolis. Most of the solar eclipses (as well as other celestial phenomena) recorded in the various dynastic histories can thus be assumed to have been observed at the appropriate capital. However, the earliest preserved series of solar eclipse observations (from any part of the world) probably does not come into this category. During the so-called 'Spring and Autumn Period' (722 to 481 BC), more than 30 solar eclipses are recorded in the *Ch'un-ch'iu*. It seems probable that most of the observations were made at the state capital, for the *Ch'un-ch'iu* notes several eclipse ceremonies taking place there.

In later times, we find occasional statements to the effect that a particular eclipse was not seen by the Astronomer Royal (e.g. on account of cloudy weather at the capital) but was reported from some provincial city instead. However, these appear to be only random sightings. Once the empire was centralised (221 BC) there is no evidence of provincial observers maintaining a systematic watch of the sky in the style of the astronomers at the imperial court.

The capital of China has been changed many times, any particular place seldom having held the honour for more than about two centuries. Often a move took place as the result of a new dynasty being established but not infrequently the change occurred on account of the loss of the original capital due to invasion or rebellion. At several periods the emperor and his court were in temporary exile, while the repeated movements of the T'ang court back and forth between Ch'ang-an and Lo-yang over several decades around AD 700 are well known to historians. We have only taken into account what we regard as the more important changes of capital. Nevertheless, there must be a degree of arbitrariness about our choice at certain critical times.

Several major Chinese cities have been known by different names at different periods. Thus, close to the site of the Former Han (202 BC – AD 9) metropolis of Ch'ang-an, the first Sui emperor founded his capital of Ta-hsing Ch'êng (AD 583). This was later (AD 618) renamed Ch'ang-an by the first T'ang ruler. At each period we have given the style by which the capital was usually known at the time, but we have avoided name changes during a dynasty.

Apart from minor periods, the capital of China has occupied a site near one of the following seven present-day cities: An-yang (pinyin spelling: Anyang), Hang-chou (Hangzhou), Hsi-an (Xian), K'ai-fêng (Kaifeng), Lo-yang (Luoyang), Nan-ching (Nanjing) and Pei-ching (Beijing). Table 1 lists in alphabetical order the various Chinese cities marked on the maps together with their geographical co-ordinates (in degrees and decimals). Note that the T'ang city of Ch'ang-an was located a little to the south-east of the Han city of the same name.

During the earliest truly historical dynasty – the Shang (c. 1550 BC to 1045 BC) – the capital appears to have changed several times. However, the details are obscure and the dates uncertain. Original Shang records – in the form of 'oracle bones' – have, however, been recovered only from a single site, the 'Wastes of Yin' near An-yang. The vast numbers of inscribed bones excavated here (Keightley, 1978) indicate the importance of the place over a considerable period. It seems possible that the capital which was traditionally called Yin occupied this site and that this is recalled in the modern name for the locality. Lacking direct evidence to the contrary, we have assumed Yin to have been the capital during the entire period from the beginning of this Atlas (1500 BC) to the fall of the Shang Dynasty around 1045 BC (Pankenier, 1984). This is almost certainly an over-simplification, but any other Shang capitals were probably in the vicinity of this place.

Table 1. *Locations of Chinese cities marked on the various maps*

Name of City	Latitude	Longitude
Ch'ang-an (Han)	34.35°N	108.88°E
Ch'ang-an (T'ang)	34.27	108.90
Ch'êng-tu	30.62	104.10
Chien-k'ang	32.03	118.78
Hao	34.16	108.72
Hsien-yang	34.39	108.85
Hsü-chang	34.05	113.80
K'ai-fêng	34.78	114.33
Lin-an	30.25	120.17
Lo-i	34.75	112.50
Lo-yang	34.75	112.47
Pei-ching	39.92	116.42
Ta-hsing Ch'êng	34.27	108.90
Ta-tu	39.92	116.42
Yin	36.07	114.33
Ying-t'ien	32.03	118.78

During the subsequent Chou Dynasty (c. 1045 to 256 BC – if we include the Chan-kuo or Warring States Period) the capital was first at Hao, but for the whole of the period after 770 BC it was located at or near Lo-i. Around 516 BC the royal residence was transferred to Chêng-chou, some 10 km to the east of Lo-i, where it remained for two centuries. However, we have felt it unnecessary to incorporate such a trivial change in position. For reference, the geographical co-ordinates of the capital of the state of Lu (modern Chü-fu) where most of the extant observations between 722 and 481 BC were probably made are: lat 35.13 deg N; long 117.02 deg E.

Finally, we come to the question of the Chinese capital at other major periods of par-

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tition, notably the Northern and Southern Dynasties (AD 420 – 589) and the co-existence of the Kin and Sung Empires (AD 1127 – 1234). In each case we have marked the metropolis of the native Chinese Dynasty (respectively Chien-k'ang and Lin-an) on the appropriate maps. However, it should be emphasised that there was also much independent astronomical activity centred largely on the site of Ch'ang-an (AD 420 – 589) and K'ai-fêng (AD 1127 – 1234). In consequence, there are many parallel reports of eclipses and other astronomical phenomena at these times.

(ii) Korea and Japan

Eclipse records from these countries cover only about the last third of the time-span of this Atlas and in order to maintain a systematic format for the maps we have not marked the sites of the appropriate capitals. Instead, we have preferred to summarise the historical background. Because of the small extent of both Korea and Japan compared with China, the spatial movements of the various capitals are relatively minor on the scale of the maps.

A significant number of eclipse records are found in the *Samguk Sagi*, the earliest history of Korea, covering the period from the 1st century BC to AD 935. However, these records are generally acknowledged to be of dubious reliability, some possibly having originated in China. The detailed history of Korea does not begin until the establishment of the kingdom of Koryŏ in AD 918, although the first eclipse record in the *Koryŏ-sa* is as late as AD 1012. However, from this time onwards, both solar and lunar eclipses are fairly regularly noted in Korean history.

The capital of Korea was Songdo (lat 37.97 deg N; long 126.58 deg E) for almost the entire Koryŏ Dynasty (AD 918 – 1392) and apart from two periods of exile, we should expect the eclipse records to originate from there. It seems likely that eclipses charted in the periods AD 1236 to 1268 and 1290 to 1292 inclusive were observed on the island of Kangwha (37.73 deg N; 126.48 deg E), to which the court had fled during periods of Mongol invasion. Soon after the fall of the Koryŏ Dynasty, the newly established Yi Dynasty moved the capital to Hanyang (modern Sŏul, 37.55 deg N; 126.97 deg E) in AD 1394. Here it has remained apart from brief periods during which no solar eclipses are charted.

The first solar eclipse record from Japan dates from AD 628 and from this time onwards eclipses are at first occasionally and later fairly frequently reported. However, the historical sources are by no means as systematic as those from China or Korea. Kanda (1935) compiled a valuable list from diaries of courtiers, temple records, etc as well as histories.

From very early times, the Japanese capital moved from one site to another in the Yamato Plain following the death of each emperor. Nara (34.68 deg N; 135.82 deg E) was established as the first fixed capital in AD 710, but the city held this position only until AD 784. For a further decade, Nagaoka (37.45 deg N; 138.83 deg E) became the imperial residence, after which the capital was established at Heian (modern Kyōto, 35.03 deg N; 135.75 deg E). Here it remained for more than a thousand years until it was replaced by Tōkyō (35.67 deg N; 139.75 deg E) in 1868.

In AD 1185, a Shogunate was founded at Kamakura (35.32 deg N; 139.55 deg E) and this became an important cultural centre. It is thus likely that a number of eclipse observations noted in Japanese history during this period were made here instead of Heian. Similar remarks apply to Edo (Tōkyō, 35.67 deg N; 139.75 deg E) between about AD 1590 and 1868, after which it became the capital.

4. Data represented on the maps

Above each map is given the following information: Julian ephemeris day number (rounded to the nearest integer), local calendar date (year, month and day) and value of $\triangle T$ used in making the various calculations. On the map itself is shown that portion of a track of totality or annularity which lies within the selected area: from 15 to 45 deg N and from 90 to 150 deg E. (The adopted sign convention for longitude is negative to the E of Greenwich). The edges of the zones of totality are shown by solid lines, those of annularity by broken lines. If an eclipse was annular for part of its trajectory and total for the remaining part the track edges are shown by solid lines. The actual phase at any particular longitude can

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be determined from the data listed below the map. Where appropriate, sunrise and sunset positions are denoted by short lines a little to the west or east of the main track and roughly perpendicular to it.

Below each map is given the degree of obscuration of the Sun at the E and W ends of the map track (over the range of longitudes listed to the right of the map). For a total eclipse, these figures will exceed 100 per cent, while for an annular eclipse the converse will be true. Where appropriate, the following additional information is supplied: (i) the greatest obscuration of the Sun along the eclipse track – if a maximum occurs in the region covered by the map; (ii) the approximate location at which the Sun rose or set centrally eclipsed, allowing for refraction and semi-diameter.

Accurate co-ordinates of an eclipse track are given in the space to the right of each map. Over a range of longitudes, usually from about 87 to 153 deg E, are given the following details: latitude of the N limit of the eclipse track, latitude of the S limit, approximate local time (in hours and minutes) of greatest phase and mean altitude of the Sun at this time. The latitude information will enable the user to draw the track on a more detailed map or investigate more carefully the local circumstances at a particular place, if required.

5. Comparison with historical records

(i) Total and near-total eclipses

Since all dates in this section directly concern eclipses, we shall use the convention of positive and negative numbers rather than the BC/AD system. Eclipses which were either total or nearly so are reported at almost all periods in Chinese history and there are occasional records from Korea and Japan. Such records are particularly prevalent in the astronomical treatises of the *Han-shu* and *Hou-han-shu* (which between them cover the period from about −200 to +220). It is instructive to compare these observations with the computed paths of totality and annularity as shown on the appropriate maps. The recorded dates, as converted to the Julian Calendar, and descriptions are given in Table 2.

Table 2. *Han records of large solar eclipses*

Julian Date	Description
−197 Aug 7	total
−187 July 17	almost complete
−180 March 4	total
−146 Nov 10	almost complete
−88 Sep 29	not complete, like a hook
−79 Sep 20	almost complete
−33 Aug 23	not complete, like a hook; it set
−27 Jun 19	not complete, like a hook
−1 Feb 5	not complete, like a hook
+2 Nov 23	total
+65 Dec 16	total
+120 Jan 18	almost complete, day became like evening

From Table 2 it will be seen that four total solar eclipses are recorded (−197, −180, +2 and +65) but without any details, although the *Shih-chi* states that on the occasion of the eclipse in −180 it became dark in the daytime. Reference to the maps shows that all but the eclipse of +2 are represented as central (only marginally so in +65) at the capital of the time (Ch'ang-an or Lo-yang) but in the case of −197 the phase was annular instead of total. It would seem that there was no separate term at this period to describe a ring eclipse; the annular obscuration of +516 is reported in the same way (in the *Nan-shih*). The observation in +2 is clearly discordant for a large change in △T would be necessary to render the eclipse central at Ch'ang-an. In fact, since the belt of totality was of virtually negligible width, the probability of the central phase actually being witnessed and reported to the capital is minute. Possibly an original report of an 'almost total' eclipse was later abbreviated.

Of the eclipses described as either 'not complete, like a hook' or 'almost complete' the relevant maps show that in −187, −146, −88, −79, −27 and −1 a large partial eclipse was indeed visible at the capital. The map for +120 makes this eclipse actually total at Lo-yang but only a small error in △T (some 3 minutes) would render the phase just partial – in keeping with the record, which alleges a very large obscuration. There was no eclipse visi-

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ble in China in −33, but the fact that the text also indicates that the Sun set while the eclipse was still visible led Dubs (1941) to suggest an alternative date of −34 Nov 1. On this occasion the Sun would set eclipsed but the dating error is difficult to explain; it will be noted that the other dates of the eclipses discussed here agree exactly with the calculated dates.

(ii) Partial eclipses

Although the main emphasis in this work is on the accurate mapping of the paths of central eclipses, most large partial eclipses visible in the Far East should also be identifiable. A rough rule for estimating the magnitude of an eclipse outside the central zone is as follows. On the scale of the maps, a displacement of 1 mm perpendicular to the edge of a track of totality or annularity will decrease the degree of obscuration of the Sun by some 1 per cent. In the case of a total eclipse, the calculated magnitude on the edges of the map track is exactly 100 per cent, so that interpolation is straightforward. However, for an annular obscuration, allowance must be made for the fact that even the central obscuration may be much less than 100 per cent (see details given below map).

If an eclipse track passes a little to the N or S of the region covered by the maps, there will be no entry for this particular date despite the fact that a partial eclipse will be produced over much of our area of interest. Hence it is apparent that this Atlas is by no means complete for *partial* eclipses visible in the Far East.

As a practical illustration of the coverage of observed eclipses of *any* magnitude we may take the case of the *Ch'un-ch'iu* record already referred to above. Between −710 and −480, this chronicle notes 37 eclipses, mostly without any descriptive details. Four of these must be presumed to be either false sightings or possibly abortive predictions since on or near the stated dates no eclipse was visible on the Earth's surface. Of the remaining 33, as many as 28 eclipses are charted here, the exceptions being of fairly small computed magnitude in NE China. A similar degree of completeness seems likely at other periods in Far Eastern history.

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