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THEORETICAL AND HISTORICAL BACKGROUND

FIRST CONSIDERATIONS: KINGSHIP AND COSMOLOGY

In the Chinese tradition shared by Korea, astronomy was both a royal duty and a royal prerogative. This had been true from time immemorial, and the Chinese ascribed the invention of astronomy to the legendary sage-emperors Yao 堯 and Shun 舜. In classical Chinese cosmology, the emperor occupied a place at the axis of the universe, mediating between Heaven and Earth. He 'sat on his throne and faced south'; ritually, if not in fact, his throne was directly beneath the pole star, and, facing south, he surveyed the whole world. The emperor had a sacred duty to promulgate an accurate calendar so that his actions could be in accord with the movements of the heavenly bodies; and he employed astronomers – who were also portent astrologers – to watch for celestial anomalies that might require an imperial response.

The rulers of kingdoms peripheral to China usually accepted this theory, and while they might acknowledge the celestial and temporal primacy of the emperor of China – the kings of Korea usually did so – they also placed themselves firmly at the *axis mundi* of their own smaller realms. Thus the Royal Observatory of the Korean Kingdom of Silla 新羅, the Ch'ŏmsŏngdae (Chan-hsing T'ai 瞻星臺, 'The Estrade for Gazing at the Stars'), built in 647 (Fig. 1.1), was also called the Pidu (Pi-tou 比斗), 'Comparable to the (Northern) Dipper'.[1] Similarly, the terrace on

[1] Jeon, STK, p. 35. See also Song Sang-yong, 'A Brief History of the Study of the Chiŏmsŏng-dae in Kyŏngju', *Korea Journal*, Aug. 1983, *23*.8: 16–21. The term Pidu admits of several possible interpretations. It could mean 'Comparable to the (Northern) Dipper', but also '(The Place for) Comparing the Dipper', i.e. observing the directional change of the 'handle' or 'pointer' of the Dipper at any given hour of the night throughout the year (its nightly directional shift is one celestial degree, i.e. $\frac{1}{365.25}$ of the celestial circle; see n. 14 below). One might also suspect here an early conflation of the similar words *pidu* 比斗 and *paedu* (*pei-tou* 北斗), 'Northern Dipper', as a name for the observational tower in popular parlance.

The 'Dipper' or 'Northern Dipper', is the well-known group of seven bright stars which are the most conspicuous part of the constellation Ursa Major. In the United States it is usually called (by coincident pictorialisation) the Big Dipper; in England it is often loosely termed the Great Bear, but the less common term the Plough is more accurate, since this refers to those seven stars alone as distinct from the entire constellation.

which stood the Japanese royal palace during the Nara period (eighth century) was known as Hokudodai (Pei-tou T'ai 北斗臺), 'Northern Dipper Terrace'.[2] These names show that the early Korean and Japanese kings accepted the Chinese cosmological principle of a connection between royal authority and celestial polar centrality. That connection being understood, it was deemed essential for any king who ruled in the Chinese tradition to engage in astronomy and calendar-making, and to employ court astronomers for that purpose. The Royal Observatory of the Yi Dynasty, the Sŏun Kwan, was charged with carrying out these astronomical, calendrical, and meteorological duties. Nevertheless, the fact that the Sŏun Kwan, and other East Asian royal observatories like it, owed their royal patronage in part to a cosmologically based theory of kingship does not mean that their methods and achievements were unscientific.[3]

THEORETICAL BACKGROUND

Although it would clearly not be possible, in these few pages, to summarise adequately the whole history of Chinese astronomy down to the end of the fourteenth century, a history that forms the proper background to the astronomy of the Yi Dynasty, we nevertheless think it useful to present here, in outline form, a few key concepts relating to cosmology, calendrical science, horology, and astronomical instruments. The reader may wish to consult in addition the list of definitions of important technical terms in astronomy to be found in the third volume of *Science and Civilisation in China*.[4]

A. Cosmology.

1. Cosmological theories. While a variety of cosmological theories (particularly the *kai-t'ien* 蓋天, 'Canopy Heaven'[5] theory) had competed for primacy in the early days of Chinese astronomy, after the Han period the *hun-t'ien* 渾天 ('Enveloping Heaven') theory was generally accepted as

[2] We are grateful to Professor Fujieda Akira of the Research Institute for Humanistic Studies, Kyoto University, for this information. Professor Fujieda conducted one of us (JSM) on a tour of the archaeological excavations of the site in 1975.

[3] N. Sivin, *Cosmos and Computation in Early Chinese Mathematical Astronomy* (Leiden: E. J. Brill, 1969).

[4] Needham, SCC III: 178–82.

[5] We employ this term as a translation for *kai-t'ien* in preference to 'Heavenly Cover', as used in Needham, SCC III. The concept involved is that heaven is shaped like the domed lid (*kai*) of an ancient Chinese bronze or ceramic vessel, or like the domed parasol canopy (also *kai*) of a Chinese chariot, covering the flat earth. The term is grammatically parallel to *hun-t'ien*, 'Enveloping Heaven'.

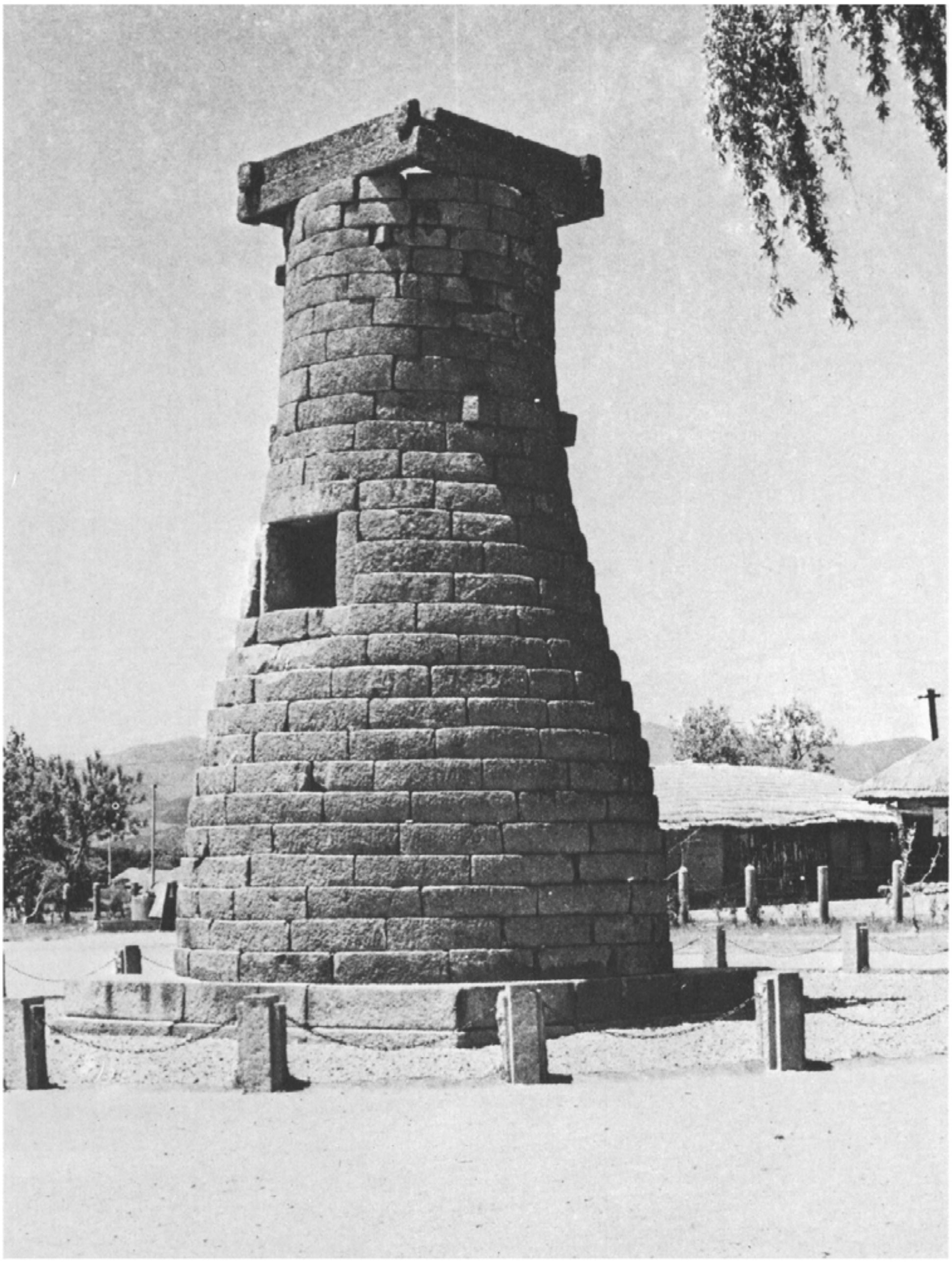

Fig. 1.1. The Ch'ŏmsŏngdae, the observatory of the Kingdom of Silla, Kyŏngju, 647 C.E. The tower was presumably used for celestial observations, and may have had instruments mounted on the platform at its apex. The tower itself may also have served as a gnomon. The square structure atop the tower has a true N–S and E–W alignment.

correct.[6] This theory assumed that the universe was spherical and centred on a flat earth. The sphericity of the earth, despite early hints in that direction, was a relatively late refinement of this theory.[7] All armillary spheres in the Chinese tradition model the *hun-t'ien* universe.

2. Equatorial-polar coordinates. From its earliest development, Chinese astronomy was equatorially based.[8] This stands in marked contrast to the ecliptic-polar basis of Western astronomy prior to Tycho Brahe. From a computational point of view there is little to choose between the two coordinate systems,[9] but the Chinese equatorial system had important consequences for the development of astronomical instruments, as we shall see below, since the mounting of armillary spheres in the Chinese tradition reflected it.
3. Divisions of the celestial sphere. For cosmological and observational purposes, the visible part of the celestial sphere was divided, in the Chinese tradition, in several ways (Fig. 1.2):[10]
   a. The five palaces. One of the simplest, and one of the oldest, divisions of the heavens was into five 'palaces'. These comprised the central circle of the north circumpolar stars (which never, for an observer in northern China, dip below the horizon), called the *tzu-wei kung* 紫微宮, 'Palace of Purple Tenuity'; and four truncated sectors extending from the circle bounding the north circumpolar stars to the south circumpolar circle of perpetual invisibility, these sectors being designated as the palaces of the East, South, West, and North. The five palaces are correlated with the Five Phases[11] (*wu hsing* 五行), the four cardinal directions (plus the centre), the seasons, etc. The four non-central palaces were symbolised by four animal emblems: the Blue-Green Dragon of the East, the Vermillion Bird of the South, the White Tiger of the West, and the Dark Warrior of the North (a paired turtle and snake).

[6] For convenient explanations of these theories see Shigeru Nakayama, *A History of Japanese Astronomy: Chinese Background and Western Impact* (Cambridge, Mass.: Harvard University Press, 1969), pp. 24–43.

[7] Needham, SCC III: 216–17; but see also Nakayama, p. 39; and Christopher Cullen, 'Joseph Needham on Chinese Astronomy', *Past and Present*, 1980, *87*: 39–53, p. 42.

[8] Needham, SCC III: 231.

[9] Cullen, p. 45.

[10] Léopold de Saussure, *Les origines de l'astronomie chinoise* (Paris, 1930), *passim*.

[11] For correlations of the Five Phases (also known as the 'five elements') see the table in Needham, SCC III: 262–3. See also John S. Major, 'Myth, Cosmology, and the Origins of Chinese Science', *Journal of Chinese Philosophy*, 1978, *5*: 1–20, pp. 11–15.

Fig. 1.2. A bronze mirror of the Middle Koryŏ period, symbolising the various divisions of the northern celestial hemisphere. From the centre: a knob representing the *axis mundi* at the north pole; the four directional animal symbols; the eight trigrams; the twelve animal symbols of the Earthly Branches, representing the Jupiter Stations; the twenty-eight Lunar Lodges and the twenty-four Fortnightly Periods. Compare the similar Chinese mirror shown in Needham, SCC III: Fig. 93.

b. The nine fields. This was similar in conception to the five palaces, except that the portion of the sky surrounding the north circumpolar stars was divided into eight, rather than four, truncated sectors. The nine fields corresponded to the 'nine continents' into which the earth was schematically divided; the eight non-central fields were correlated with the eight trigrams of the *I ching* 易經 (Book of Changes).

c. Jupiter Stations. The equator (and, by analogy, the ecliptic) was divided into twelve 'Jupiter Stations', reflecting the ancient idea that the (approximately) twelve-year orbital period of Jupiter (and, more specifically, of *t'ai-sui* 太歲, an invisible counter-orbital correlate of Jupiter) was of great astrological (or, more properly, chronomatic) significance. The twelve Jupiter Stations were correlated with the twelve months and with the twelve 'Earthly Branches' (*chih* 支) of the sexagenary system for enumerating days and years. The Earthly Branches were in turn correlated with symbolical animals; the Jupiter Stations did not, however, equate to the twelve Signs of the Western zodiac.[12]

d. Lunar Lodges. The equator was also divided into twenty-eight unequal sectors called Lunar Lodges (*hsiu* 宿), defined by twenty-eight constellations lying mostly near an ancient celestial equator. This too was a system of great antiquity,[13] related to the similar Indian *nakshatras* (which also played a significant role in Islamic astronomy). The Lunar Lodges were derived from the $27\frac{1}{3}$ days of the moon's sidereal period, but anciently they were also commonly correlated with the $29\frac{1}{2}$-year orbital period of Saturn, approximated as 28 years. The location of celestial bodies within the Lunar Lodges was an important consideration in East Asian portent astrology.

[12] The term 'Chinese Zodiac' is the result of a misconception. See J. H. Combridge, 'Chinese Sexagenary Calendar-Cycles', *Antiquarian Horology*, Sept. 1966, 5.4: 134; and also 'Hour Systems in China and Japan', *Bulletin of the National Association of Watch and Clock Collectors, Inc.*, Aug. 1976, *18*.4: 336–8.

[13] The earliest extant list of all twenty-eight *hsiu* is found on the lid of a lacquer box, dated approximately 433 B.C.E., recently excavated in Hupei, China, and now in the Hupei Provincial Museum, Wuhan. See Wang Chien-min 王建民 *et al.*, 'Tseng Hou-i mu ch'u-t'u ti erh-shih-pa hsiu ch'ing-lung pai-hu t'u-hsiang' 曾侯乙墓出土的二十八宿青龙白虎图象 (On a picture of the twenty-eight Lunar Lodges, the Blue-Green Dragon, and the White Tiger, excavated from the tomb of the Marquis Yi of Tseng), *Wen-wu* 文物, 1979.7: 40–5. See also Needham, SCC III: 231–59. Some of the extensive literature in Chinese on the origins of the *hsiu* is cited in Xi Zezong, 'Chinese Studies in the History of Astronomy, 1949–1979', *Isis*, Sept. 1981, *72*: 456–70, p. 463.

e. Fortnightly Periods. The tropical year was divided into twelve equal periods, *ch'i* 氣, defined by 30° of solar motion along the ecliptic. These were subdivided into twelve 'mid-point *ch'i*' (*chung-ch'i* 中氣) and twelve 'nodal *ch'i*' (*chieh-ch'i* 節氣), making a total of twenty-four Fortnightly Periods nominally of 15 days but on average 15.219 days each. These periods were in effect a series of sub-seasons that defined an agrarian solar calendar for everyday use. In practice the Fortnightly Periods were counted in whole days, with extra days inserted as necessary to account for accumulated fractional days.

f. Degrees. Finally, the equator, the ecliptic, and all other celestial circles were divided into $365\frac{1}{4}$ 'degrees' (*tu* 度).[14] The replacement of this number by the 360 degrees of a circle as reckoned in the West was a consequence of the introduction of Jesuit methods into Chinese astronomy.

B. The calendar.

1. Nature of the calendar. A Chinese calendar (*li* 曆) was not merely a device for keeping track of days and seasons, but rather a system of astronomical calculations that yielded a complete ephemeris of celestial motions. Its most important task, and most serious difficulty, lay (as Nakayama has noted) in 'reconciling two fundamentally incommensurable periods – the tropical year and the synodic month'.[15] The calendar had also to reconcile the tropical year with the sidereal year. A satisfactory calendar was expected also to predict solar and lunar eclipses with accuracy; and although Chinese calendrical science devoted relatively less attention to the orbital periods of the five visible planets, such matters as conjunctions, occlusions, oppositions, and other phenomena of planetary location within the Lunar Lodges and in relation to each other were important in portent astrology and demanded a certain amount of attention.[16]

2. Calendar reform. The magnitude and complexity of the task faced by the designers of Chinese calendars, and the difficulties of precision plotting of

[14] In order to prevent any ambiguity between Western degrees and the slightly smaller Chinese celestial degrees, throughout this book the former will be denoted by the conventional superscript°, and the latter by a superscript^{d} (denoting both 'degrees' and 度 in its *pinyin* romanisation *du*). Thus, for example, a circle consists of 360° and $365\frac{1}{4}^{d}$.

[15] Nakayama, p. 67.

[16] *Ibid.* pp. 150–1.

celestial orbits in the absence of the telescope and, more important, an adequate theory of celestial mechanics, meant that calendars inevitably accumulated errors and had to be revised from time to time. The Bureau of Astronomy often tended to consult the calendar rather than the stars for reckoning celestial time, but when the differences between the two became too great, the making of a new calendar was one of the Bureau's most important tasks.[17]

3. The political significance of calendar reform. The proclamation of a new calendar was an essential symbol of the assumption of imperial authority by each new Chinese dynasty. The 'new' calendar might be simply the previous dynasty's calendar under a new name, with or without minor revisions, or it might be a truly new and reformed calendar. New calendars were sometimes also promulgated, with appropriate rituals, during the lifetime of a dynasty. The kings of Korea, as tributary vassals of the Chinese emperor, had no choice but to accept and respond to these new calendars as they appeared.

C. Timekeeping. The Chinese day began at midnight. The Hebrew/Greek custom of beginning the day at sunset was unknown in the Chinese tradition. The Chinese day was divided in several ways:[18]

1. Twelve 'double-hours' (*shih* 時), each corresponding to two hours of Western time. The double-hours were divided into halves, named for their 'beginnings' (*ch'u* 初) and 'mid-points' (*cheng* 正). Their timing was such that midnight and noon came at the 'mid-points' rather than at the 'beginnings' of the corresponding double-hours; that is, the double-hours ran from 11 p.m. to 1 a.m., 1 a.m. to 3 a.m., etc.
2. One hundred equal intervals called *k'o* 刻, each corresponding to 14 min 24 sec of modern (Western-derived) time-reckoning. The *k'o* were sub-divided into fractions, called *fen* 分. Because each double-hour corresponded to $8\frac{1}{3}$ *k'o* and each half-double-hour to $4\frac{1}{6}$ *k'o*, the number of *fen* was usually six or some multiple thereof. With the adoption of Western time-reckoning in China in the seventeenth century, the name *k'o* passed

[17] *Ibid.* p. 67.
[18] Jeon, STK, pp. 87–93; Needham, Wang, and Price, HC, pp. 199–205.

into general use for integral quarter-hours, each of 15 Western minutes (to the latter of which the word *fen* was applied).[19]

3. Night-watches. In addition to the two forms of constant 'clock-time' just mentioned, the Chinese divided each nominal night, between the officially defined times of 'dusk' and 'dawn' (or, anciently, between sunset and sunrise), into five equal but seasonally variable 'night-watches' (*keng* 更), each of which was divided into five equal portions (*tien* 點 or *ch'ou* 籌). Because of the cyclic variation in the length of the night over the course of a year, the automatic striking (on drums and gongs) of the night-watches and their divisions, and the moments of 'dusk' and 'dawn' as well, presented a formidable (and elegantly overcome) problem to the designers of timekeeping instruments in the Sino-Korean tradition.[20]

D. Instruments. As we have noted, Chinese astronomy was equatorial rather than ecliptic in orientation; it was also arithmetical-algebraic rather than geometrical in its methods. Chinese astronomers showed little interest in formulating intellectual models of the cosmos of the sort that dominated Western astronomy from Aristotle to Copernicus and Tycho Brahe and beyond. Whether this was, on the whole, an advantage or a disadvantage (or neither) for Chinese astronomy in the long run is a matter of debate; it did, however, have important consequences for astronomical instrumentation in the Chinese tradition.

1. Chinese instruments, from the Han 'diviner's board' (*shih* 式)[21] and the Later Han armillary spheres of Chang Heng 張衡 onwards, were equatorial in their reference.[22]
2. The armillary sphere, along with the gnomon, was the fundamental

[19] To avoid ambiguity as to the actual time-spans involved, in this book we confine the translations 'quarter-hour' and 'minute' to instances where the modern senses are appropriate. Where the older senses of *k'o* and *fen* are concerned, we employ the translations 'interval' and 'fraction', adding the Chinese words in romanisation in parentheses where necessary to indicate that the terms are used in a technical sense to denote specific periods of time. The word *k'o* means literally a 'notch' or 'mark' on a timekeeping scale; our term 'interval' is not, strictly speaking, a translation, but rather is a paraphrase intended to emphasise that the word denoted a precise interval of time.

[20] Needham, Wang, and Price, HC, pp. 37–9; John H. Combridge, 'The Astronomical Clocktowers of Chang Ssu-hsun and his Successors, A.D. 976 to 1126', *Antiquarian Horology*, June 1975, *9.3*: 288–301, p. 293; Jeon, STK, pp. 88–93; Needham, SCC IV.2: 517–18.

[21] Donald Harper, 'The Han Cosmic Board (*shih* 式)', *Early China*, 1978–9, *4*: 1–10. See also Christopher Cullen, 'Some Further Points on the *Shih*', and Donald J. Harper, 'The Han Cosmic Board: A Response to Christopher Cullen', *Early China*, 1980–1, *6*: 31–46, 47–56.

[22] Needham, SCC III: 342–54 *et seq.*

instrument of Chinese-style observatories. The equatorial basis led to a variety of other instruments as well, such as the equatorial sundial and Kuo Shou-ching's 'equatorial torquetum', the Simplified Instrument (*chien-i* 簡儀).

3. The equatorial basis suggested the desirability and mechanical feasibility of armillary spheres (*hun-i* 渾儀) and celestial globes (*hun-hsiang* 渾象) that were rotated automatically.[23]
4. The automatic rotation of instruments began, so far as surviving records show, in the time of Chang Heng (*c.* 117 C.E.) and reached a high point with the great astronomical clocktowers made by Chang Ssu-hsün 張思訓 and his successors, including Su Sung 蘇頌 and associates, during the Sung period. These clocktowers were powered by great 'timekeeping water-wheels',[24] the operating principles of which were based conceptually on those of the steelyard clepsydra.[25] These wheels found no direct descendants among the automatic timekeepers of Korea, however. The latter were based instead on other types of clepsydral technology[26] imported from Central Asia into China during the Yüan period.

We conclude this introductory section by noting that the immediate influences on the astronomy and instrumentation of the Korean Royal Observatory at the beginning of the Yi period were Kuo Shou-ching's Shou-shih 授時 'calendar' (more accurately, a complete system of astronomical calculations) of 1280,[27] his full set of instruments for the Chinese Imperial Bureau of Astronomy of about the

[23] *Ibid.* 359–66.

[24] Needham, Wang, and Price, HC, *passim*; John H. Combridge, 'The Celestial Balance', *Horological Journal*, Feb. 1962, *104*.2: 82–6; Needham, SCC IV.2: Fig. 658; Combridge, 'Astronomical Clocktowers'; Combridge, 'Clocktower Millenary Reflections', *Antiquarian Horology*, Winter 1979, *11*.6: 604–8.

[25] Needham, Wang, and Price, HC, p. 57, n. 2, para. 4; p. 94.

[26] Donald R. Hill, ed. and tr., *On the Construction of Water-Clocks: Kitāb Arshimīdas fī 'amal al-binkamāt* (London: Turner and Devereux, Occasional Paper No. 4, 1976); Hill, *Arabic Water-Clocks* (Aleppo, Syria: University of Aleppo Institute for the History of Arabic Science, 1981); Needham, Wang, and Price, HC, pp. 88, 97, 121ff, 140, 163, 186–7, and Fig. 34.

When we began this study we had expected to find that at least some of the mechanical timekeepers of Korea during the Yi period were directly descended from the Sung timekeeping waterwheel clocktowers of Chang Ssu-hsün *et al.* (see n. 24 above), and we were surprised to find that such is not the case as far as the driving mechanism is concerned. No doubt the Sung instruments stimulated the *idea* of mechanical timekeeping in Korea as well as in post-Sung China. But the Korean instruments, as we shall see in Chapter 2, belong primarily to a Sino-Arabic clepsydral tradition; only the time-annunciating jackwork of the Sung clocktowers was reflected in their design.

[27] Nakayama, pp. 123–50.