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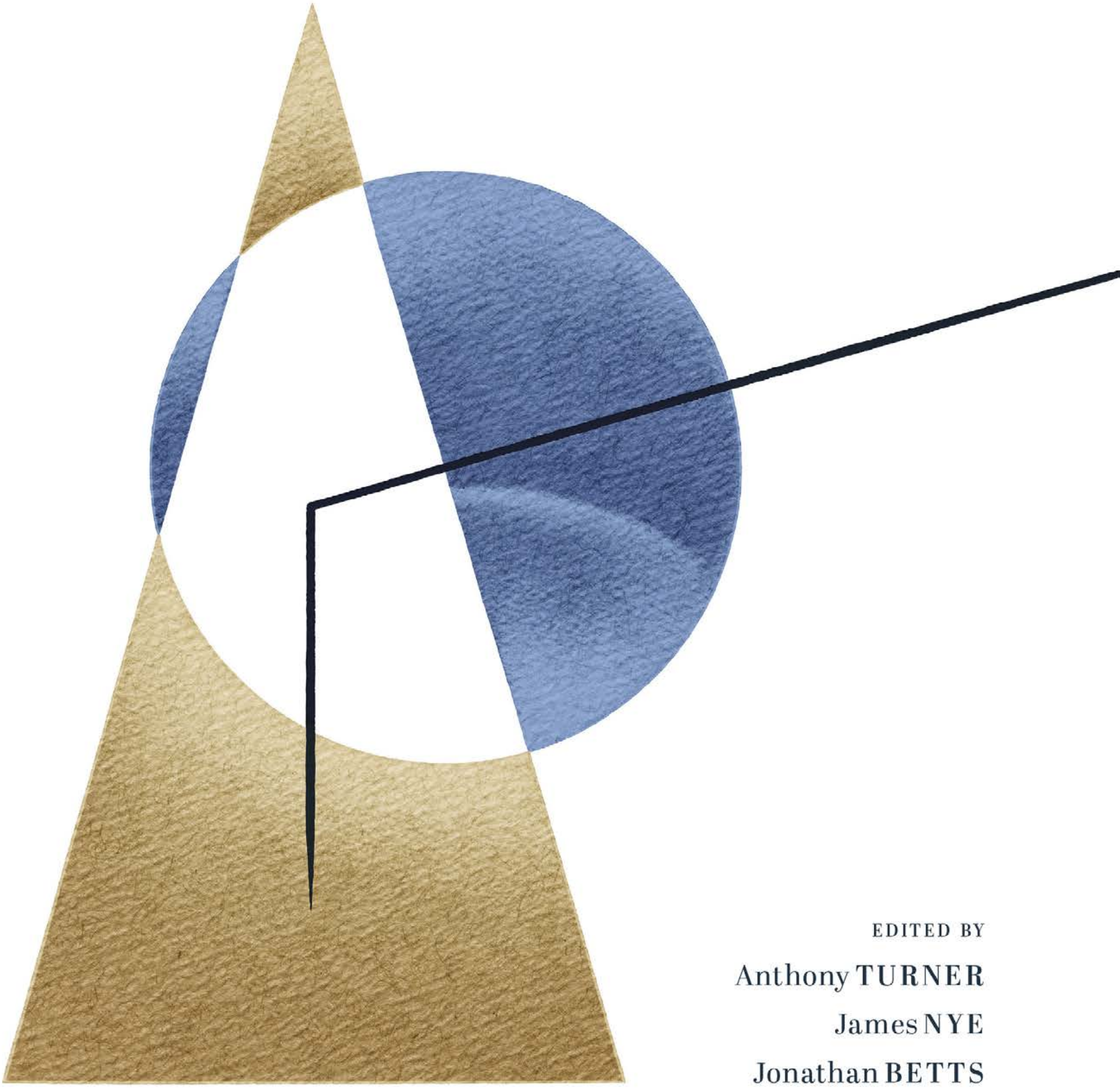
A GENERAL HISTORY OF HOROLOGY



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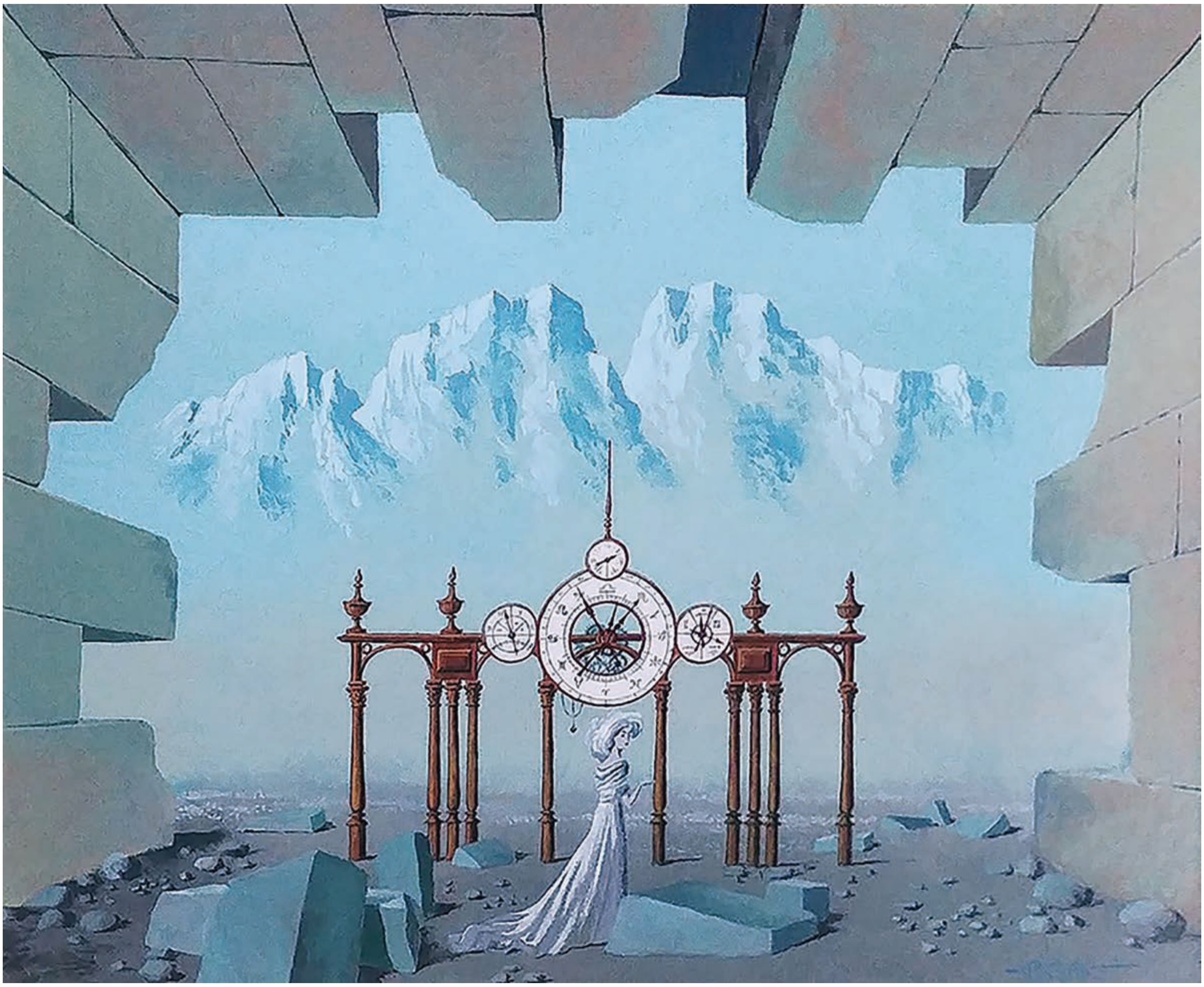

Gaston Bogaert, *Le Passé*.

An architect, theatre designer, and graphic artist who taught at the l'Ecole supérieure des techniques de publicité, Brussels, the Franco-Belgian Bogaert (1918–2008) worked in the surrealist tradition of Magritte and Delvaux. Philosopher, he published several works: *Procès d'une métaphysique* in 1980, *Propylées* in 1988. In 1989, he accompanied his exhibition at the Galerie 2016 with an essay entitled *L'Enigme du temps*. Time is one of his major sources of inspiration and reflection. Refined and poetic, constantly renewed, the compositions of Bogaert display his ideas on the fall of civilizations, the enduring time of nature, and the ephemeral time of humanity. Mechanical clocks often appear in the 'figuration spiritualisée' of his conception of the world. In *Le Passé*, he evokes the ruins of a lost civilization which are opposed to the eternal force of nature represented by the snowy summits of the mountains. In the centre, a young woman, allegorical of human temporality, indicates a complex monumental skeleton clock in the form of a gateway. Bogaert himself said of *Le Passé* that the clock carries a message of hope, not one of ineluctable destruction.

Oil on board, 54 × 65 cm, 1989, private collection.

Title Page Illustration

The seal of an 'Horlogiarius', 'Robert the clockmaker from (?)Yarmouth', *c.*1300. © York Archaeological Trust, GB. Reproduced by permission.

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OXFORD
UNIVERSITY PRESS

OXFORD
UNIVERSITY PRESS

Great Clarendon Street, Oxford, OX2 6DP,
United Kingdom

Oxford University Press is a department of the University of Oxford.
It furthers the University's objective of excellence in research, scholarship, and education by
publishing worldwide. Oxford is a registered trade mark of Oxford University Press in the UK
and in certain other countries

Supported by Sotheby's

Impression: 1

British Library Cataloguing in Publication Data

Data available

Library of Congress Control Number: 2021936263
Data available

ISBN 978-0-19-886391-5

DOI: 10.1093/oso/9780198863915.001.0001

Printed in Great Britain by
Bell & Bain Ltd., Glasgow

To write down all I contain at this moment
I would pour the desert through an hour-glass,
The sea through a water-clock,
Grain by grain and drop by drop
Let in the trackless, measureless, mutable seas and sands.

Kathleen Raine, 'The Moment', 1946.

Today most professional historians 'specialise'. They choose a period, sometimes a very brief period, and within that period they strive, in desperate competition with ever-expanding evidence, to know all the facts. [. . .] Theirs is a static world. They have a self-contained economy, a Maginot Line, and large reserves which they seldom use; but they have no philosophy. For a historical philosophy is incompatible with such narrow frontiers. It must apply to humanity in any period. To test it, a historian must dare to travel abroad, even in hostile country; to express it he must be ready to write essays even on subjects on which he may be ill-qualified to write books.

Hugh Trevor-Roper, *Historical Essays*, 1958, Foreword.

. . . time that brings all things to ruin, perfects also everything.

Thomas Browne, *Pseudoxia epidemica* (1648), 1672, 302.

CONTENTS

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INTRODUCTION

Horology in modern usage designates the entire range of time-finding, time-keeping, and time-telling instruments with the exception of calendrical instruments. Since 1899, when F. J. Britten published his *Old Clocks and watches and their makers*, a work that, despite its defects, remained in print for nearly a century and is still consulted, there have been few attempts at a complete survey of the development of horology apart from Willis I. Milham, *Time and timekeepers . . . ,* 1923 (reprint 1975) and David S. Landes, *Revolution in time, clocks and the making of the modern World*, 1983 (revised French edition 1987; extra-illustrated edition of the French translation without revision of the text, 2017). Apart from these, the only substantial work to have appeared, but restricted to Europe, is that by Giuseppe Brusa, *L'Arte dell' orologeria in Europa, sette secoli di orologi meccanici*, Milan, 1978. A new general survey of the history of horology is therefore desirable.

Such a survey is the more needed because a very considerable amount of new research on the development of horology has been carried out in the last five decades. Most of this, however, has been published in the journals of national societies for horology and its history and unites collectors, museum curators, historians, and practising clock- and watchmakers worldwide. It is now therefore appropriate to attempt to synthesize this new knowledge from several languages and sources of limited circulation into a single, large-scale volume offering a general survey of the whole subject, thus enabling it to be considered in a long perspective. We are conscious that this is not complete. Australia and New Zealand, for example, have a minimal presence and horological trade from Europe to the Americas is also, like the role of publicity and advertising in horological marketing, only briefly mentioned. All are casualties to the exigencies of space.

HOROLOGY, THE WORD

'The term horology is at present more particularly confined to the principles upon which the art of making clocks and watches is established'.[1] Such is the earliest instance that the *Oxford English Dictionary* offers in support of its definition of horology as 'the art or science of measuring time; the construction of clocks and watches'.[2] The formulation by the authors of the *Pantologia*, however, suggests that the term had already been in use for some time but had changed its meaning. This is certainly the case. 'Clock, in *Horology'* begins the article of that name in Rees' *Cyclopedia*.[3] Horology is here used as a collective noun that embraces all that is defined in *Pantologia* or the *OED*. Despite the date of publication (1819–20) affixed to the completed work, Rees' *Cyclopedia* was actually issued in parts between 1805 and 1813 with many of the articles on clock- and watch work, all written by William Pearson F.R.S. (1767–1847), appearing in 1807.[4] 'Horology' as a collective noun, therefore, was clearly employed in the early 1800s, perhaps even before, coming into use shortly after a corpus of systematic writing on the subject was developed by such writers as Alexander Cumming (1733–1814), Thomas Hatton (*fl.* Pre-1757–74), and Ferdinand Berthoud (1727–1807) in the third and fourth quarters of the eighteenth century.[5]

The word, however, did not arise from a void. As a singular noun, 'horology' has a far longer presence in English. 'An horology', or its many variant forms,[6] from the fourteenth century onwards had the general meaning of 'an instrument for telling the hour'. This is clearly expressed by Thomas Blundeville in 1594 when explaining that 'the most part of horologies or clockes in the east countries . . . ' marked twenty-four hours.[7] The word

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[1] Good, Gregory & Bosworth 1819, v.

[2] *OED* 1972, i, 1332: 391.

[3] Rees 1819–20, viii, sig. 373^{r}. The opening of the article 'Chronometer' is similar 'Chronometer, . . . , is a term in *Horology*,', Sig. B1^{r}.

[4] Harte 1973, 92*ff.*

[5] For their works, see Bibliography.

[6] Listed in OED 1972, i, 1332: 390; see also Robey & Linnard 2017, 193.

[7] Blundeveille 1594, f. 172v. A similar use is *Othello* II. 3: 'He'll watch the horologe a double set/If drink rock not his cradle'.

could be applied to sundials, as by John Wycliffe in his commentary on Isaiah xxxviii: 8 (1382) 'the shadowe of lynes bi the whiche it hadde go doun in the oriloge'[8] or, a few years later, by Chaucer as a synonym for a clock when vaunting Chauntecleer, whose crowing was more reliable than 'a clokke or an abbey orlogge'.[9]

Any kind of time-measuring instrument then could be described as an horology, although Thomas Powell restricted the term to devices 'which by the motion of several Wheels, and Springs, and Weights, and couterpoizes should give an account of the time, without Sun or Stars.'[10] Nevertheless, Sir Thomas Browne (1605–82) tells us, 'Before the daies of *Jerom* there were Horologies, and several accounts of time; for they measured the hours not only by drops of water in glasses, called Clepsydræ, but also by sand in glasses, called Clepsammia'.[11] The word could also take an adjectival form. In the earliest book in English devoted to sundials, Thomas Fale (*fl.*1586–1604) explained that he had omitted the 'Horological Cylinder';[12] when he eventually published the universal equinoctial ring dial, William Oughtred (1575–1660) described it as *the generall horologicall ring*;[13] and the earliest book in English devoted exclusively to clocks and watches appeared under the title of *Horological Dialogues*.[14] As an adjective, even in the seventeenth century, 'horological' seems to have held a more general meaning than the noun, and this would eventually lead to a generalization of the sense of 'horology' to describe the entire subject.

It is this generality of meaning that 'horology' has acquired since the early nineteenth century that explains and justifies the inclusion, in a general history of the subject, of sundials, fire-clocks, pneumatic clocks, and sand-glasses, which all depend upon different principles from the water-weight, solid-weight-, and spring-driven devices that constitute the greater part of the matter to be treated here. The origin of the term is the Greek *horologion*, a noun compounding *hora*, hour (and by extension time) and *logion*, indicator, or shower. In old English and French generally written in some such form as *orlogge*, *orloge*, *orologge*, or *oriloge*, mediation through the Latin *horologium* led the aspirate 'h' of the Greek to become a written consonant, and to the use of a medial 'o' as in modern English 'horologe', although the latter failed to maintain itself in modern French *horloge*. This, although its etymology has never been in doubt, had serious gender problems, but the generality of the term is displayed by Dominique Jacquinot who, explaining how to find the difference of longitude between Paris and Lyon by comparing the time shown by his clock or watch (which had been set by his astrolabe on departure), with that found using his astrolabe on arriving, describes the former as his 'monstre d'horloge' to make the distinction between the two instruments clear.[15] Modern Italian *orologio* kept the medial 'o' but without the consonantal 'h', while Spanish *reloj* (via old Catalan *relotje* and *orollotje*) decapitated the earlier forms, as also occurred in France in the regions of Berry and Burgundy, where *reloje* was used. In general, the shift from the singular name of the object to a collective name for the making of the objects took place in the mid- to later eighteenth century: 'horology is the art of making machines which, by means of wheelwork, measure time by dividing it into equal parts, and indicating this division by intelligible signals.'[16] Fuller than that offered by the *Dictionnaire* of the Académie Française,[17] such a definition, as Jaubert makes clear in his following paragraphs, reflects a new perception of the clockmaker's craft as an art based on scientific principles.[18]

HOUR SYSTEMS

Hour systems have varied widely across both time and space. The natural time division upon which they all depend is the day defined as the total period of daylight and darkness that elapses between two sunsets, two sunrises, or two other definable moments. This period can be treated as a single unit—the ***nychthemeron***—and uniformly divided up, or as two distinct units—that of daylight and that of darkness—each of which may be separately and uniformly divided. Because of the change in solar declination throughout the year, however, the period of daylight and the period of darkness are equal to each other only at the spring and autumn equinoxes, these being the mid-points of the half-year from the winter solstice to the summer solstice (during which the daylight period lengthens) and the half-year from the summer solstice to that of winter (during which the daylight period declines). In consequence, a uniform division of the daylight period will not be equal to a similar uniform division of the dark period, nor will the lengths of the divisions of either remain equal from day to day. Hours obtained in this way are therefore doubly unequal and are thus designated *unequal* hours. Uniform

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[8] Cited from OED (n. 2).

[9] Geoffrey Chaucer (*c.*1368), 'The Nun's Priest's Tale' (line 34), cited from Robinson 1957, 199. It is of course possible that Chaucer was here using the words as alternatives, not synonyms in which case the distinction must be between a clock sounding the hours, and a monastic alarm. See, however, the suggestion by Robey & Linnard 2017, 193 that in other contexts the distinction made is between the clock movement and the dial. Barrington 1778, 422 thought a bell and a clock were in question.

[10] Powell 1661, 6.

[11] Brown 1672, ch. V. xvii, 301.

[12] Fale 1593, aiii^{v}.

[13] Oughtred 1652.

[14] Smith 1675.

[15] For the gender of *horloge* see Havard 1887–90, ii, 1292–3; Maddison 1994. For the longitude, see Jacquinot 1545 f. 52^{v}.

[16] Jaubert 1773, ii, 401.

[17] 'The art of making clocks, pendulum clocks and watches', *Dictionnaire* 1772, i, 611.

[18] Specific terms in horology also repay investigation. On the term 'foliot', for example, see Bradley 2015, Linnard 2015, and Robey 2015.

division of the total period of light and dark (the solar day), however, provides intervals that are invariable. These are designated *equal* hours. Other terminology has been used. *Seasonal, variable*, or *temporal* may be found used for *unequal hours*, and *equinoctial* or *invariable* for *equal* hours.

Both the number of hours contained in a day (or a day and night period), and the point from which the count is begun, are arbitrary. The origins of the double twelve-hour count familiar in much of Europe seem to lie in third millennium BCE Egypt.[19] Before this, however, the Egyptians probably distinguished four periods in the solar day–night: two periods of twilight and daylight, and darkness. These were subdivided to twelve, daylight to ten and the periods of twilight to one each. In Rome, two different systems were used:

1. a 'natural day' of twelve hours counted from sunrise to sunset in unequal hours, and an equivalent 'natural night' counted from sunset to sunrise, with the hours gathered into groups of three hours each, the 'vigils', generally used for everyday communal life.
2. a 'civil day', in which the night was considered as an integral part of the day with a count of twenty-four hours starting from midnight, generally used for civil and legal purposes.

In China,[20] three main systems have existed. One system divided the ***nycthemeron*** from midnight to midnight into 100 *ke* (notches or graduations). A second system divided it into twelve *shi* (double hours), the first of which was divided by midnight. Each *shi* was given the name of one of the signs of the Chinese zodiac. The sequence therefore was

11pm–1am	*zi*	rat	11am–1pm	*wu*	horse
1am–3am	*chou*	ox	1pm–3pm	*wei*	sheep
3am–5am	*yin*	tiger	3pm–5pm	*shen*	monkey
5am–7am	*mao*	hare	5pm–7pm	*you*	cock
7am–9am	*chen*	dragon	7pm–9pm	*xu*	dog
9am–11am	*si*	snake	9pm–11pm	*hai*	boar

A third system divided the night from sunset to sunrise into five equal parts called *geng:*

Rigu	sunset
Hun	dusk
Chugeng	10 *ke* after dusk
Diadem	period of waiting for dawn
Xiao	dawn

The first two of these are **equal hour** systems, the third, an **unequal hour** count.

In Japan, the so-called Edo hours were determined by dividing the astronomical day in two: day and night based on dawn and dusk (not on sunrise and sunset) and dividing each into six equal parts. Therefore, an Edo hour was equivalent to two hours on average, and people called it *toki* (時). A *toki* is roughly equivalent to a double hour, similarly half a *toki* (*han-toki*, 半時) is equivalent to a single hour. Edo hour names start with 9 (*kokonotsu*, 九つ) at 12:00 midnight, then subtract successively by 1 from 9, which gives 8 (*yatsu*, 八つ), 7 (*nanatsu*, 七つ), dawn 6 (*ake mutsu*, 明け六つ), 5 (*itsutsu*, 五つ*)*, and 4 (*yotsu*, 四つ). The count then starts again with 9 at 12 noon and proceeds as before 8, 7, dusk 6 (*kure mutsu*, 暮れ六つ), 5, and 4. The hour names originated from the number of times the temple bell was struck in ancient Japan, as *Engishiki* showed. This curious system of declining hour numbers follows from the fact that 9 is a significant number in *Onmyo* thought. By multiplying the number from 1 to 6 by 9, numbers 9, 18, 27, 36, 45, 54 are obtained. Subtracting ten places from each number gives the number of the reverse order. These hours were tolled by the time bells, *tokinokane* (時の鐘).[21]

In India, the *Taittirīya-Brāhmaṇa* and the *Satapatha-Brāhmaṇa* (*c.*700–600 BCE), two texts of the Vedic corpus, divide the civil day into thirty *muhūrtas*. The *Vedāṅga-jyotiṣa* (*c.*400 BCE), also a part of the Vedic corpus, divides the *muhūrta* into two *nāḍikās*. Accordingly, the civil day is divided into sixty equal units of *nāḍikās* (later called *ghaṭīs*). This became the standard unit of time measurement and remained so until the end of the nineteenth century.

The *Vedāṅga-jyotiṣa* subdivides the *naḍikā* into ten 1/20 *kalās*, a *kalā* into four *pādas*, a *pāda* into thirty-one *kāṣṭhās*, and a *kāṣṭā* into five *akṣaras*. Other texts contain different subdivisions. In the early sixth-century Āryabhaṭa (BCE 476) standardized these into a sexagesimal system, parallel to the sexagesimal division of the circle into minutes, seconds, and so on:[22]

Nychthemeron = sixty *nāḍikās (*each of twenty-four minutes)
one *nāḍikā* = sixty *vināḍikās* (each of twenty-four seconds)
one *vināḍikā* = sixty *guru-akṣaras* (time to utter one long Sanskrit syllable, approx. 0.4 second)

In this system, the sixty *nāḍikās* are an unequal hour count. While the duration of the *nāḍikās* remains constant, the number of *nāḍikās* from sunrise to sunset or from sunset to sunrise varies according to local latitude and the seasons.

Most societies have a variety of terms to designate divisions of the day, but these being subjective are neglected here although they could give rise to quantified systems. These, in early societies, tended to be used only in religious and dynastic contexts, while the use of equal hours was virtually exclusive to astronomers. In Antiquity and the Middle Ages, the hours of everyday life throughout Europe, the Near East, and India were the unequal hours. In Europe these were gradually abandoned from the fourteenth century. In Islamic regions, where the unequal hours were

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[19] Neugebauer & Parker 1960, 120.

[20] For details see Bedini 1994, 14–15.

[21] Urai 2014; Robertson 1931, 198–203.

[22] Aryabhaṭa 1976, 85–6.

intimately linked with prayer times, and in Japan, unequal hours remained customary.

However, conversion to equal hour measurement in Europe did not lead to the harmonizing of hour counts:

- Italian (or Bohemian, Czech, Silesian, Polish, or Welsh) are hours counted 1–24 from sunset or a little after. Gradually abandoned from the seventeenth century onwards, they nonetheless maintained themselves in Italian usage until well into the nineteenth century.[23]
- Babylonian or Greek hours counted 1–24 from sunrise.[24]
- Nuremberg hours were counted from sunrise and sunset, each point being considered 0 as in the unequal hour system. The count however was an equal hour count of the unequal periods of day and night. Thus an early summer day would count from sunrise to sunset up to 13 hours 10 minutes. At sunset, the count would begin again although the night would only extend to 10 hours 50 minutes.

Variants could be found in other German and Central European regions. Basel, for example, employed a double twelve-hour count but began it at 11 p.m. and 11 a.m. Astronomers everywhere used the double twelve-hour count beginning the day at noon, while the same count, but begun at midnight (known also as 'common hours') was typical of France, Britain, and Northwest Europe. In all cases, however, the time employed was, at least until the end of the eighteenth century, local time, so even within the confines of a single country, the time of day varied with difference of longitude.

CONVENTIONS

On the first mention of a person in the text (this can be ascertained from the index), his/her dates are given in full. If exact dates are not known they are given in the form *c.*1921–*c.*42 where there can be a presumption that the actual date(s) though unknown was/were within five to ten years of the date(s) offered. Where there is greater uncertainty but at least one definite date is known, *fl.* 1921 is used. Where no more than a period can be indicated, this is indicated as 2nd half 8th century. Biographical details of makers are generally not given but can be readily ascertained from the several national dictionaries and other lists that are available.[25] The appearance of a technical term in **bold** type in the text indicates that it is explained in the glossary. A few terms are included in the glossary but appear very frequently throughout the book. These have therefore been set in **bold** only on their first appearance in each chapter. References in the notes are given by author's name, date of publication, and page; these key to the bibliography. Discussions of works in the text may, however, have a fuller citation.

Chapters 1, 8, 13, Section 3, 13, Section 4, 15, 20, and 23 were originally written in French and have been translated by Anthony Turner.

ACKNOWLEDGEMENTS

The editors' first gratitude must go to the authors for accepting arduous assignments and patiently tolerating our exigencies; equally to the staff of the Oxford University Press for undertaking the work and giving it physical form, in particular to the editorial team of Sonke Adlung, Francesca McMahon, and Sharmila Radha who have been helpful and supportive throughout. Our thanks also to Sotheby's London, whose sponsorship has enabled the work to be colour-printed and for a professional index to be compiled. Well beyond the call of duty, Roger Smith has helpfully commented on several chapters besides writing his own. The following have offered us advice, encouragement, and answered questions: Katy Barrett, Alun Davies, Peter de Clercq, John Davis, Jennifer Speake, and Tony Weston. The debts of individual authors are acknowledged in their several chapters.

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[23] Arnaldi 2007; Dohrn-van Rossum 1996, 114, and Catamo 2008. From at least the sixteenth century onwards in Italy the hour count was begun half an hour after sunset so as to coincide with the ringing of the bell for the *Angelus* prayer. The origins of this custom are in doubt. Tailliez n.d. suggests distinguishing hours counted from sunset itself (however defined) as italic hours, and those counted from thirty minutes after sunset as *Italian* hours. The distinction, however, does not work in Italian. See Arnaldi 2006, 2007; Dohrn-van Rossum 1996, 114; Catamo 2008; and Schneider 2017. The last known use of Italian hours was for the meridian line constructed in 1891 in the church of San Giorgio, Modica, Sicily.

[24] *Nuovo Almanacco per l'anno bisestile 1776 arricchito di notizie utili e dilettevoli*, Venezia [1775/76], 52, notes that 'the Greeks nowaday are the only ones, who begin the day at sunrise.'

[25] Abeler 1977; Basanta Campos 1972; Chenakal 1972; Fraiture 2009; Loomes 2006; Morpugo 1972; Patrizzi 1998; Pipping, Sidenbladh & Elfström 1995; Pritchard 1997; Sposato 1983; Tardy 1972; Turicchia 2018.

CHAPTER ONE

TIME MEASUREMENT IN ANTIQUITY

Jérôme Bonnin

To write the history of horology before Antiquity is next to impossible. It is only in 'historical' periods—those from which textual evidence has survived—that the historian can find traces of the material organization of time in simple or complex systems that permit the synchronization of human activity. Many elements remain unknown. How time was thought of in Antiquity has no answer, for an exact study of the history of time, and theories and concepts about it, is still needed. In this volume it is more appropriate to deal with the reality of time as experienced in everyday life, rather than to engage in speculation about the concept of timekeeping, which, even if it reveals an approach (essentially that of the elite), is rather far removed from the actual principles and practice of horology. The notion of time, however, is important in literature.[1] More than the Greeks, the Romans attributed a material reality to time, and linked it to their everyday life and to the success of their projects. For the Romans, it was a philosophical rather than a divine reality—a natural entity that did not unfold by chance. Time seemed to be controlled not by a divinity, but by natural laws.[2] The Romans had an essentially materialist attitude that linked the idea of time to the purely material matters of daily activity, work, and business of all kinds. It is to the Romans that we owe ideas, like Horace's 'Beware of seeking what tomorrow will bring; profit from the day whatever destiny may bring you', that relate time with both eternity and enjoyment of the moment.[3] Even so, reflection about the measurement of time largely precedes Græco-Roman Antiquity.

THE ORIENTAL ORIGINS OF TIME MEASUREMENT

The origin of time measurement is an insoluble question. The origins and forms of the first time-measuring instruments are also unknowable. It would be illusory to examine all the geographical regions and civilizations known from Antiquity seeking to disinter traces of such instruments. In discussing time measurement, two cultures demand attention—Egypt and Babylon—although only a brief survey of what is known can be given here.

The Egyptians divided the day from dawn to sunset into twelve equal parts, each part having a specific name.[4] The oldest witness to a division of day and night into twenty-four parts occurs in a twelfth century BCE papyrus preserved in Cairo.[5] The oldest known time-measuring instruments also come from Egypt, as do the oldest writings about them; it was there also that the first idea of 'divine' time developed with a need of instruments to measure it.[6] Time was a major element of civilization, although this aspect is often not recognized. The obelisks, for example, were not parts of **sundials** or meridians in Ancient Egypt.[7] Schematizing, it can be said that time measurement in Egypt has two major elements: the creation of several sundial-type instruments that nonetheless had no later influence, and the perfecting of effective hydraulic instruments

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[1] For a complete study of the subject see Baran 1976, 2–20.

[2] Seneca, *Letters* 101, 'Time unfolds according to strict but impenetrable laws'.

[3] Horace, *Odes*, I, 9, 10.

[4] For Egyptian hour divisions, see above, 'Introduction'. For hour names, see Maddison & Turner 1999, 126–129.

[5] Museum of Egyptian Antiquities, Cairo: Inv. no 86637. Concerning this text, the division of time and Egyptian astronomical concepts more generally, see Clagett 1995, 98ff.; Neugebauer & Parker 1960, 114.

[6] See Symons 1999, whose section on 'Shadow Clocks and Sloping Sundials', 127–51, is currently the definitive treatment of the subject; see also Symons 2002.

[7] Symons 1999, 128, n. 130.

Jérôme Bonnin, *Time Measurement in Antiquity*. In: *A General History of Horology*. Edited by Anthony Turner, Jonathan Betts, and James Nye, Oxford University Press.
© Oxford University Press (2022). DOI: 10.1093/oso/9780198863915.003.0001

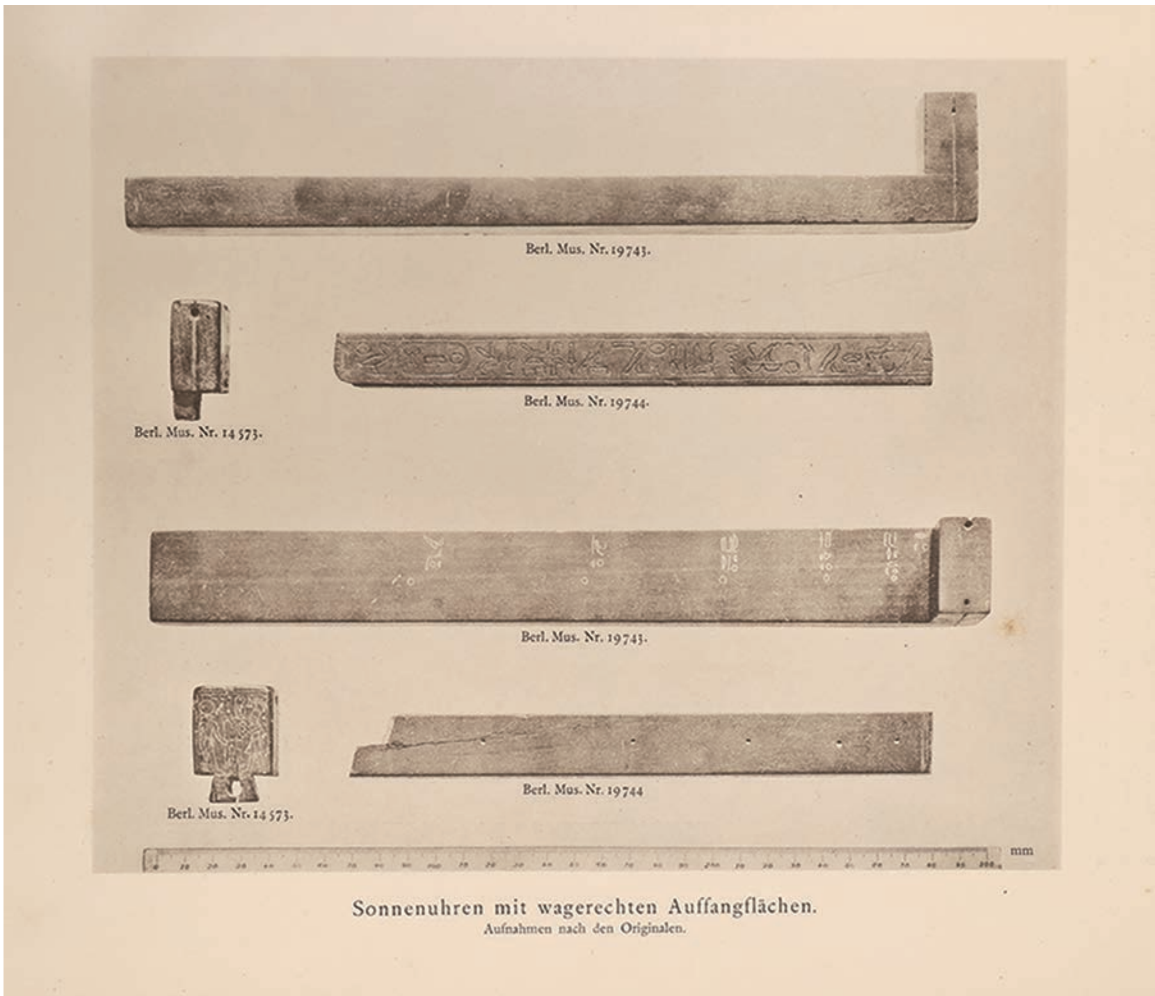

Figure 1 Ruler-type Egyptian shadow clocks, Berlin Museum after Borchardt 1920, pl. 12. Photo: Jean-Baptiste Buffetaud.

of a kind that can still be found used at Rome in the first century CE and linked with religious ceremonies. In Egypt, solar instruments were of greater number, and with a specific way of operating, time being indicated by the length of a shadow rather than by its direction. It is this system that later became habitual.[8]

The oldest known instrument indicating time by the length of the **gnomon** shadow dates from the time of Thutmose III (first half fifteenth century BCE)[9] and several examples are known (Figure 1). The device is formed of a rule with a rectangular block at one end. A small hole and a guideline worked in this block serve to fix and allow the use of a plumb line to level the instrument. The upper surface of the rule is pierced with five small holes with the corresponding name of the hour sometimes marked beside them, beginning at sunrise. Once levelled, the instrument is pointed towards the Sun so that the shadow falls exactly on the rule, the hour being read from the position of its tip. The device is not especially accurate as the hour positions were determined empirically, not by calculation. This is confirmed by examining the relation between the height of the gnomon-block and the spacing of the hour holes, which seem to be standardized on the known examples. Further examination of these dials also shows that they were only really usable in Egypt from the end of spring to the beginning of autumn. Therefore, their use (quite different from **water clocks**, which deployed **unequal hours**) seems to have been reserved for specific tasks, mainly religious, the instruments taking on standard forms that lasted throughout the Egyptian period.

This 'ruler-type' dial was probably the precursor of the inclined plane dial, apparently developed between the seventh and sixth centuries BCE. Used as offertory objects in the sanctuaries, several examples have survived, most of them complete.[10] They are composed of a stone block carrying at one end a rectangular gnomon-block and facing it a similar prismatic block, but with the upper face cut at an angle to form an inclined plane. The gnomon-block has a rectangular cavity with a vertical line incised beneath it as a guide for the plummet. Abridgements of the Greek names of the Egyptian months are marked on the top of the

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[8] For a recent attempt to classify Egyptian Sundials, see Symons & Khurana 2016.

[9] Berlin, Ägyptisches Museum, Inv. no 1974. Such an instrument is depicted and described in a pictorial inscription in the Cenotaph de Seti I, Abydos (*c.* 1291–78 BCE). Frankfort 1933, ch. viii.

[10] See Bosticco 1957, 33–49.

Figure 2 Dial from the Valley of the Kings after Bickel & Gautschy 2014. Photo: © University of Basel, Kings' Valley Project, M. Kacicnik.

angled block and seven lines corresponding with them are incised on the inclined face of the instrument. Also set along each of these seven lines are six points placed at unequal intervals, their distance diminishing from the top to the bottom. They are used in a way similar to that of the first group, except that the gnomon shadow falls on the inclined plane and not on a horizontal rule. As before, once levelled they are pointed towards the Sun, with the time being read on the line corresponding with the month. Despite a more refined conception and a smaller size (an average length of 120mm), they pose problems of accuracy and use like those of the first group, particularly as no account appears to have been taken of latitude in their construction.

Beside these two relatively well-documented types of dial, which even supplied the graphism for some hieroglyphs signifying 'sundial', there may have existed a further, more problematic, group, of which four examples are known.[11] These appear to use the *direction* of the gnomon shadow, not its *length*, i.e. they act as vertical **direction dials**. One from Gaza and one discovered by a University of Basel excavation team (Figure 2) are the oldest, dating from the thirteenth century BCE. The two others are Græco-Roman and could have been influenced by the vertical plane dials of this period. Discussion of these objects today concerns their function and the nature of the lines and hour system that they show—if they are indeed sundials. A semicircular face is divided by lines that converge towards the centre into twelves sectors of 15 degrees each. This design raises alternative hypotheses. Firstly they are dials showing **equal hours**, which implies that the Egyptians of the thirteenth century BCE knew of the **polar gnomon**, although there is no other attested historical evidence. Secondly, the objects show a moment of time by means of the shadow of a straight gnomon set at right angles to the graph on the surface. A further difficulty is the positioning of these dials, as there is no means of attaching them to a support, and the user has to orient them, which presupposes knowledge of the north–south direction; this was uncommon in Antiquity and required a lengthy period of measurement to determine it, so the utility of a portable dial is lost. In sum, it seems best to consider these objects simply as solar pectorals and to exclude them from the corpus of Egyptian sundials.

Just as the oldest solar instruments derive from Egypt, so do the oldest **outflow water clocks**. The earliest archaeological referent for an outflow water clock dates from the reign of Amenhotep

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[11] The first was found at Gaza in the early twentieth century but its present whereabouts is unknown. The second, found at Luxor, is preserved in Berlin (Inv. no 20 322), the third in Brussels (Inv. no E 7330). The last was found in 2013 in the Valley of the Kings by Swiss archaeologists. See Gautschy & Bickel 2014.

III (*c.* 1415–1380 BCE).[12] It is an alabaster vase in the shape of a truncated cone graduated on the inside wall with hour marks placed as functions of the twelve months. At daybreak or sunset, the vase was filled with water, which flowed out slowly though a small orifice worked in the base. The time was read on the inner wall using the month scale appropriate for the time of the year. This was not entirely straightforward in low light, and the meniscus could hinder locating the exact level of the water in the restricted space of the vase. A much-later papyrus (third century BCE) found at Oxyrhynchus gives some indications about the construction of such instruments.[13] The document is written in Greek by a Greek or Hellenistic bureaucrat, probably summarizing an Egyptian technique transmitted down to the Ptolemaic period. This kind of instrument would still be found many centuries after their creation in some temples of Isis during the Roman period.

What was the use of these solar and hydraulic instruments? The most plausible hypothesis is that they had religious rather than civil use. No surviving text about them refers to their use in everyday life. They were most probably employed in the cults to order the hours of prayer and the services to be rendered to the Gods. The fact that all the known examples of both classes of sundial are portable suggests that they were not permanent but could be used for religious ceremonies inside or outside the temples. Moreover, many of these instruments have been found in funerary contexts together with other cult or everyday objects intended to serve the dead person in afterlife.

All this raises an important point concerning time-measuring instruments in the Græco-Roman period. The Greeks seem to have inherited little from Egyptian civilization. Egyptian instruments, apart from the water clocks, are unique and have hardly any equivalents in later periods; this may be due to their unreliable nature, a function of their essentially ritual, religious role, which made them inappropriate for civil time measurement. An omnipresent religion, personified in the Pharaoh, furnished explanations for the order of the universe and its movement. Thus, time instruments were not linked technically with the natural imperatives of unequal hours, latitude, and seasonal variations, but with religious ritual. This, however, was not the case for the civilization of Babylon (second millennium BCE—mid-first century BCE)—another culture that made far-reaching explorations into time measurement.

The Babylonians would influence all the peoples of the Mediterranean basin, and in particular, the Greeks. They would produce exact documents about the movements of the planets, the Moon, and the stars. Complex ephemerides would be drawn up in order to predict events (notably eclipses), to establish the religious calendar, or to construct horoscopes. It is well known that these 'Babylonians' attained a high level of scientific knowledge—notably in mathematics and astronomy—from the eighth century BCE onwards. That they should have made time-measuring instruments is well-founded and corroborated by Greek and Roman testimony. By contrast with Egyptian and later periods, the soil of Babylon has yielded neither sundials nor water clocks, with the exception of one small **sinking bowl** vessel.[14] Is this the result of chance operating in archaeological investigation, or were such instruments generally created from perishable materials like wood? Moreover, the documents about time keeping that exist from the Babylonian empire are extremely succinct (unlike for mathematics and astronomy) and fall into two groups: those concerning the measurement of a quantity of liquid, and those concerning the measurement of a shadow. The first group consists of two kinds of text: tablets containing mathematical problems and exercises (such texts actually mention an instrument, the *maltaktum* or *didbibdu* in Akkadian, and give its height and diameter, but not the timescale); and tablets that specifically discuss the linked subjects of astronomy and astrology—principally the first of the *Mul-Apin* tablets.[15] The latter give information about the volume (expressed as weight) of a liquid escaping from a container without any details as to the form or name of the container. These were identified as water clocks.[16] Specialists suggest that, known in Mesopotamia from the eighth century BCE onwards, they were prismatic or cylindrical in shape and operated on the **outflow** principle. Whatever the case, the instrument seems to have been definitive for all astronomical measurements that included a lapse of time. The frequency with which they are mentioned in astronomical and mathematical texts throughout the first millennium BCE shows to what degree they were considered indispensable.

The second group of instruments is still more problematic than the first. It would be simplest to say that no text exists with a description of an instrument that could be interpreted as a sundial or a gnomon and that we therefore know nothing about them. However, sources do exist, although only a few cuneiform tablets mention the measurement of a shadow—the second clay tablet of the *Mul-Apin* series dated between the tenth and the eighth century BCE.[17] This tablet tells us that, to determine the relationship between day and night, the length of the day should be

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[12] That some, less developed, outflow clocks of cylindrical or prismatic form existed in second-millennium Babylon is clear from texts concerning them, which are interpreted by Michel-Nozières, 2000.

[13] P. Oxy. III no 470. Borchardt 1920, 10–14 and plates 7a, 7b interprets and reproduces this text.

[14] This was found at Nimrud by David Brown (Brown 2000, 103–22). It is a pierced bowl weighing 250g preserved in the British Museum, London (inv 91238). In form it recalls other sinking-bowls known from other cultures notably India (see Chapter 2, Section 1 and Sarma 2008, ch. 5), the Far East (e.g. two bowls, one from Colombo and one from Sri Lanka also in the British Museum, inv As 1946.0708.17 135gr; As1898.0703.291.a) and the Maghreb (see Glick 1969), and BM inv Af 1952.23.1 from Tolga, an irrigation timer that sinks in between four and five minutes). The Babylon bowl is a short duration timer (Fermor & Steele 2000, 214–15 and 220–1), and remains isolated, a *unicum*.

[15] *Mul-Apin* II. i, 10, 24, first published in King 1912.

[16] Brown, Fermor, & Walker 2000, 130–48; Hoyrup 1998, 192–4.

[17] *Mul-Apin* II. ii, 21–42, first published by Weidner 1924.

measured by a ‘shadow instrument’; but that this is a sundial is only a hypothesis. The measure of a shadow is noted, but no specific instrument is mentioned. This problem of nomenclature is a constant in Babylonian writings on time. The second, and last, evidence must also be treated with caution. It is found in two highly fragmented tablets,[18] which include in the introduction a phrase translated as ‘if you wish to construct a gnomon . . .’. So a term supposed to mean ‘gnomon’ exists in Sumerian u_4*-sakar*, which gives *uskaru* or *askara* in Akkadian. However, these tablets are of a very late date, possibly even from the Hellenistic period, and even if the term originates in an earlier period, it is no proof of the age of the instrument.

If these direct sources are of doubtful interpretation and little can be derived from them, the secondary sources are not any clearer. The oldest is Greek and is a well-known passage in Herodotus (480–25 BCE):[19]

> For the Greeks learned the *polos* πόλοσ, and the *gnomon* (γνώμονα), and the twelve parts of the day from the Babylonians.

These two lines have caused much ink to be spilt. The testimony is more complex than it looks, for it is the first Greek text that clearly mentions instruments for the measure of time. Setting aside the problems associated with the terms *polos* and *gnomon*, what is important here is the Babylonian origin of the one or two instruments mentioned, as well as the reference to the ‘twelve parts of the day’. There is no need to doubt Herodotus concerning the Greek debt to Babylonian knowledge for mathematics, astronomy, and astrology. That Herodotus mentions it in the fifth century BCE implies that such knowledge was known and used in Greece from the sixth century BCE or even earlier. It was on the basis of this inheritance that the Greeks would develop their own idea of astronomy and gnomonics using all the geometrical skills we know they possessed.

GREEK TIME MEASUREMENT: SUNDIALS

The origin of time-measuring instruments in Greece is much debated. The fundamental instrument was the gnomon, the first astronomical instrument used, and from which sundials derived. Herodotus first mentions them in the fifth century BCE, which poses serious difficulties of interpretation, notably for the terms *polos* and *gnomon*. These words relate to no known archaeological vestiges and produce only hypotheses. Given the context and the mention of the division of the day into twelve hours, it seems logical to suppose that the *polos* and the *gnomon* are two different instruments used to divide up the day. However, other sources suggest that originally the ‘gnomon instrument’ was used for more than determining the hour. Anaximander of Miletus (d. post-546 BCE), one of the great names of ancient astronomy, is associated with this device. Unfortunately, all sources about him were written long after his period.[20] Diogenes Laertius (first half of the third century CE) claims Anaximander as the inventor of the gnomon, but we must consider this statement with caution. If a gnomon is simply a stake thrust into the ground in order to measure variations in shadow length, no one in particular has a claim to its invention. If we consider it as a more complex device incorporating a gnomonic scale that allows the day to be divided, the attribution to Anaximander falls foul of Herodotus’ evidence, as well as that the Babylonians had divided up the day with the aid of a complex instrument probably similar to a gnomon well before Anaximander. Often, in consequence, the text of Diogenes is explained by the supposition that Anaximander did not invent the gnomon but introduced it into Greece from Babylonia. However, all the sources concerning Anaximander are unanimous that he used the gnomon to determine the seasons, the solstices, and the equinoxes.

The oldest use of the gnomon was indeed probably to indicate the solstices. It is for that reason moreover that it was called a heliotrope (ἡλιοτρόπιον), ‘index of the variations of the Sun’. Perhaps its first mention is in Homer’s *Odyssey*, although in a rather obscure form.[21] Later sources attest to the existence of large instruments of this kind. The legendary Pherecydes installed one on the Island of Syros;[22] others mentioned are those of Thebes,[23] and of Syracuse dated to the fourth century BCE cited by Plutarch (46–125 AD).[24] It is far more likely that these early instruments served to determine the dates of the solstices and the equinoxes

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[18] Sachs 1955, No xxxiv.

[19] Herodotus, *Histories*, ii 109.

[20] Anaximander’s work is known firstly from a passage in Pliny (*Natural History*, ii. 78), According to him the gnomonic art can be traced back to Anaximenes (*fl.* 546–25), Anaximander’s pupil, who should have been the first to erect a gnomon in Lacedaemonia. However, this differs from the evidence of Diogenes Laertius, *Lives and Opinions of the Philosophers* (probably written second century CE), according to whom it was Anaximander, Anaximenes’ teacher, who first discovered that the length of a gnomon shadow varied with latitude and that it was he who invented the gnomon. Placing the construction of such an instrument in Lacedaemonia agrees with Pliny. Eusebius in the fourth century CE further mentions Anaximander, and the last source concerning him is the *Suda* (tenth century CE).

[21] *Odyssey*, xv, 403–4. Eumaeus speaks of his country, the Island of Syra (Syros), where the ‘variations of the Sun’ are found. Szabo & Maula 1986 discuss the possible interpretations of this passage and conclude that it refers to a heliotrope.

[22] Diogenes Laertius, i, 119: ‘His heliotrope is also preserved on the isle of Syros’.

[23] Polybius, *Histories*, v 99.8. The description of preparations for the siege of Thebes by Philip mentions the place where a third of the army was stationed, a place called ‘heliotrope’.

[24] Plutarch, *Life of Dion*, 29. ‘At the foot of the fortress and the Pentepyles, there was an immense heliotrope visible from afar, which had

than to give the hour. Anaximander in the sixth century BCE was perhaps not the inventor of the gnomon, but the first to use it to calculate correctly the date of the equinoxes.

Herodotus, however, does not only speak of the gnomon, but also of the *polos*—a highly uncertain term. If the gnomon he mentions is only a simple pole planted vertically in the ground, then the term designates only that which stands above the soil. Could not the *polos* correspond with the plane receiving the shadow cast by the gnomon, perhaps a surface other than the ground—a plate of wood or stone, fixed or not, engraved—a carrier of the indications? *Polos* has various meanings: 'terrestrial pole', 'celestial pole', 'the heavens which turn around these poles', or even 'sundial'.[25] On this basis, the *polos* is traditionally, and still generally today, considered to be the ancestor of the spherical dial, the *scaphe*. The meaning, 'celestial vault', and the resemblance to this of the spherical sundial are the principal reasons for the association. Only a few scholars reject the idea.[26] This rejection is reinforced by a passage from Athenaeus (*c.*170–*c.*223 CE). It is difficult to conceive that a dial called a *polos*, made 'in imitation of the heliotrope of Achradine', could have been a spherical type of dial, notably because up to this point the heliotropes are always characterized by their monumental aspect and, following from this, are generally horizontal. Moreover, only a rather limited horizontal dial could imitate a heliotrope and not a spherical dial.

The last point mentioned by Herodotus, the division of the day into twelve parts, seems almost an anecdote. Certainly, the day was divided into twelve since the Egyptians and the Babylonians; the idea is not new. However, examining the phrase more carefully raises a problem. Does Herodotus speak of a division into hours? If so, what kind of hours? The idea of the hour applied to the twelve divisions of the day is known with certitude among the Greeks from the end of the fourth century BCE and seems to have become an everyday term about the same time. Earlier than this, it was a technical term specific to astronomy. Moreover, the astronomical hour was not the same as the hour of everyday life. The Greeks made a clear distinction between **equal hours** and **unequal hours**. The first were used essentially for astronomical observations and calculations. They appear in Greece shortly before the fourth century BCE and were probably used by Eudoxus (408–355 BCE). The second refers to the **unequal hours** given by ordinary sundials. These the Greeks used in everyday life. When it is stated in a text that an event occurred at the sixth hour, that does not mean 6 o'clock in the morning or the evening, but midday since, at least among the Romans, the hours were counted from daybreak to sunset. The night period was also divided into twelve parts and was counted from sunset to sunrise. Since unequal hours are not easily assimilable to modern hours, Table I shows the correspondences between modern hours and those for the latitude of Rome (most of the texts to be cited in what follows derive from the Italian peninsula) and is calculated using 24 degrees as the value of the obliquity of the **ecliptic**.[27]

Table I Concordance of the unequal hours of Antiquity with modern equal hours

Latitude 42° **Obliquity 24°**	**Summer solstice**	**Equinoxes**	**Winter solstice**
Sunrise	4 h 25 m	6 h	7 h 35 m
1st hour	5 h 41 m	7 h	8 h 19 m
2nd hour	6 h 57 m	8 h	9 h 03 m
3rd hour	8 h 13 m	9 h	9 h 47 m
4th hour	9 h 28 m	10 h	10 h 32 m
5th hour	10 h 44 m	11 h	11 h 16 m
6th hour	12 h 00 m	12 h	12 h 00 m
7th hour	13 h 16 m	13 h	12 h 44 m
8th hour	14 h 31 m	14 h	13 h 28 m
9th hour	15 h 47 m	15 h	14 h 13 m
10th hour	17 h 03 m	16 h	14 h 57 m
11th hour	18 h 19 m	17 h	15 h 41 m
12th hour	19 h 34 m	18 h	16 h 25 m

Herodotus spoke of the division of the day into twelve hours in the context of astronomical instruments, not that of everyday life. It follows therefore that he was probably referring to **equal hours**. These could have been known to Greek astronomers even earlier than the fourth century BCE, given that the Babylonians already used them. Therefore, the text should probably be read as 'the division of the day into twelve equal parts'. That Herodotus does not use the word 'hour' is certainly because in the fifth century BCE the term was normally used to designate 'season' and would not have been understood as 'hour' by his readers.

GREEK TIME MEASUREMENT: WATER CLOCKS

The Babylonians and the Egyptians not only developed methods and instruments for finding and measuring time by the Sun, but also probably transmitted the first instruments for measuring time using water. The clepsydra is perhaps one of the oldest means. Etymologically the word κλεψύδραν signifies 'water thief'. It derives either from the name of a rather insignificant rivulet in Athens or from a quite specific utensil. In the sixth century BCE, experiments on various pneumatic and hydraulic phenomena

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been installed by Denys'. Denys the Old lived 431–367 BCE. It was probably the work of his son.

[25] Diels 1920, 157. Some uses: Euripides, *Orestes*, i, 1685 (the size and the geometric characteristics fifth century BCE) in the sense of 'celestial vault'; Aristophanes, *Geryatedes* (fr. 8739,11 N), in the sense of 'sundial', although in the *Detalien* its use is equivalent to 'heliotrope'; Moschion as reported by Athenaeus (v. 207e) mentions a structure placed on the ship of Hieron II of Alexandria, a ship supposed to have been constructed under the direction of Archimedes: 'On the roof a sundial (*polos*) is found in imitation of the heliotrope of Achradine'.

[26] Diels 1920, 157, n. 1; Hannah 2009, 71–2.

[27] Table calculated by Denis Savoie.

provoked the creation of a device that is today known as a 'toddy lifter': a pierced hollow body fitted with exit tubes that can be stopped with a finger and, as with a pipette, raise water, wine, or oil from a container. The possibility of slowing the outflow, or observation of the slow immersion of such a body in a liquid could have led to adaptation of the device for determining a lapse of time.[28] This latter interpretation is the most probable, as it was only in the fourth century BCE that the Athens rivulet received the name of 'clepsydra'. If the instrument could serve scientific, astronomical, and military purposes from the fourth century BCE and medical from the third century BCE, it was primarily in the judicial realm that it would develop. It is certain that in the fifth century BCE this device was used in the courts to measure (and limit) the length of orations. Speeches were made as a function of 'water', not as a function of 'time'.

> Is it decent thus to ruin a blameless old man before the clepsydra (κλεψύδραν), a comrade who has laboured much, who so many times has been in a hot and glorious sweat, a veteran who fought at Marathon for the Republic?[29]

Aristophanes' plays date from the late fifth century BCE. They contain the earliest references to the judiciary use of the clepsydra, yet already the term serves as a metonym for the court—the instrument has become customary, habitual. Its use may date from well before the beginning of the fifth century BCE with the development of democracy. Use of the clepsydra as a way of limiting the length of speeches so as to ensure an equitable distribution of time to all is linked with the world of politics and civic life.

A fortunate discovery allows us to know the form and the characteristics of one such clepsydra dated to the fourth century BCE from the archaeological context in which it was found.[30] It takes the form of a terracotta vase with a thickened rim and two handles (Figure 3).

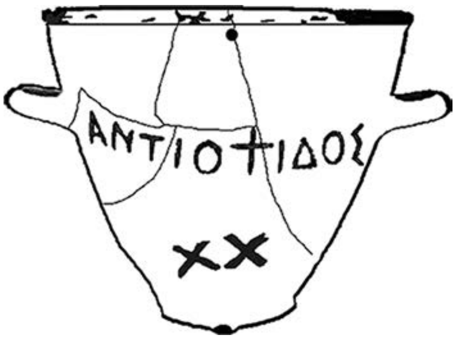

Figure 3 Clepsydra from the Athens *Tholos*. Drawing by J. Bonnin after Young 1939.

An upper orifice placed just below the rim serves as an overflow to evacuate excess water. An orifice at the base, with an inset tube of bronze, allows water to escape into a second vessel. The interior of the vase is covered with an impermeable glaze, and the exterior carries the inscription 'Antiochidos' followed by 'XX'. Antiochidos is the name of an Athenian tribe, and 'XX' represents the capacity of the vase, which is two *choes*, the equivalent of 6.4 litres. This quantity allowed the orator to speak uninterruptedly for six minutes. Evidently, there would have been different clepsydras in the courts, their capacity related to the importance of the process. Like weights and measures, the standards for these clepsydras would have been kept in the *Tholos* or *Skias*, which served as the 'depot for the standards'. It was obligatory to place the instrument where all could see it.

If the clepsydra sufficed for judicial needs, it did not give the hour, even if some adjustments (before the invention of large water clocks) could have allowed the transformation of these 'timers' into instruments to show time. It was by means of clepsydras that military watches were regulated (devalued in periods of time on the model of a 'timer', not of a timekeeping clock). Such a system did not show an hour but only measured the elapse of a period of time. It was perhaps to allow all citizens to know the time of public assemblies that large, hour-showing clocks were developed, such as that installed on the Agora at Athens and close to the most important tribunals. Constructed on the same model as a clepsydra, it had instead a capacity of 1,000 litres, although its flow rate is indeterminable.

This clock was discovered in 1953 in the southwest corner of the Agora, although it was not immediately identified as such. Only the unusual layout of the construction, which had no resemblance to that of public fountains or other water-using systems, led the archaeologist Vanderpool to deduce that it was a water clock, a hypothesis confirmed twenty years later by Armstrong and McCamp.[31] Ceramic matter found in the infill of the foundations and around the clock suggest that it was erected towards the end of the fourth century BCE and underwent many subsequent repairs and adaptations. It probably ceased to be used during the second century BCE. A second, large-capacity clock existed at Oropos where the fourth century BCE site has been conserved and well analysed.[32] Two clocks in the Agora at Samos are mentioned in a decree from the second century BCE.[33] From these gnomonic and hydraulic appliances the Romans would derive their techniques and instruments.

TIME PIECES IN ROME: AN UNPRECEDENTED DIFFUSION

If the Romans invented only a few instruments, they took up Greek techniques, employed Greek artisans, and developed time

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[28] Dohrn-van Rossum 1996, 22–3.

[29] Aristophanes, *The Archanians*, 694.

[30] Young 1939, 274–84.

[31] Armstrong & McCamp 1977; for technical details, see 147–61.

[32] Theodossiou, Katsiotis, Manimanis, & Mantarakis 2010, 159–67.

[33] Thompson & Wycherley 1972. For the decree itself see *SEG*, 41, 711.

measurement in cities in a unique way, thus turning it into an indispensable element of civilization. The first mention of clocks in Roman history is by Pliny the Elder (23–79 CE)[34] who, in a long passage, presents 'the third agreement between peoples', i.e. a scientific notation of the hours. He relates that this arrived only late in Rome, from the fourth century BCE onwards, and in his *Natural History* he tells us that the first dial appeared in Rome in 293 BCE, an unproblematic date, since dials were known well before in Greece. But Pliny also recounts Varro's version that the first dial appeared in 263 BCE, at the beginning of the Punic War, when a Greek dial and its accompanying hours arrived in Rome as war booty from the Greek Sicilian city of Catania. Finally, in 164 BCE the censor Quintus Marcius Philippus had the first dial calculated for the latitude of Rome installed, contrasting with that drawn for Catania, which the Romans had nonetheless used for ninety-nine years. Varro (116–27 BCE) also tells us that a water clock was installed in Rome at the latest by 159 BCE:

> *Solarium* designates the dial on which the hours are seen from the Sun, or the clock that Scipio Nasica placed in the shadow of the Basilica of Emily & Fulvia.[35]

This remark proves that a need to know a fixed hour, even during the night, must rapidly have developed. It is difficult to conjecture the form of the instrument, but its location suggests a large, sophisticated device.

The story of the dial from Catania is frequently cited in modern studies of Roman timekeeping. Reading the text of Pliny and other later writers leaves an impression that the Romans blindly obeyed an 'imprecise' sundial for ninety-nine years without knowing it. But, some corrections should be made. Firstly, it is probable that the Romans noted the error but accorded little importance to it given that they rarely had need of exact hours. What is important is that the entire community refers to the same hour regardless of its precision. Moreover, the error in question was perhaps not as upsetting as might be thought.[36] The anomaly evoked by Pliny is always explained by the removal of the dial from Catania to Rome.[37] If, as according to Denis Savoie, it would be impossible to recognize that the dial indicated an incorrect hour, it was possible, by contrast, to realize that the dial was not adapted for use in Rome. As Savoie notes

> if one removes a horizontal dial from Catania to Rome, the shadow of the gnomon at Noon will always be longer than in Catania whatever the date. Since the Greeks terminated the hour lines at the hyperbolic arc for the winter (and summer) solstice, it follows that an hour-reading would be impossible around the winter solstice since the shadow would go well beyond the winter arc.[38]

This leads him to suppose that it was by the inappropriate length of the gnomon as well as the shadow that, given that it was correctly oriented, the error of the dial could be seen. This proposition is convincing and leads us to question Pliny's insistence on this unimportant error. He seems to stigmatize excessively the lack of scientific knowledge among the Romans. Is this an example of what Paul Veyne calls the superiority/inferiority complex of the Romans in relation to the Hellenes?[39] Once the dial of Marcus Philippus was erected, the Romans had an instrument calculated for the latitude of the leading city and no longer needed to depend on a foreign one to control political and daily life.[40]

Roman literature is not lacking in early references to time, nor about the earliest dials and their role. Their introduction was rapid and left profound traces. A passage in *The Beotien* is interesting in this respect:[41]

> May the gods damn the man who first invented hours, and especially he who first installed a sundial here: to my distress he has cut up my day in slices. When I was a boy my belly, the best and most exact of clocks, was my dial. In any place, it told me when to eat, except when there wasn't anything. Now, even if there is, one eats only by permission of the Sun so much the city is full of dials. Already most of the population languish, dried out by hunger.

The author of this comedy takes up here a commonplace conceit of the Greeks—the hanger-on complaining about the introduction of timepieces into private life. Critics generally accept that this piece by Plautus (*c.*250–*c.*184 BCE) dates from the late third century BCE. The outburst certainly has comic effect, but the piece also gibes at the recent introduction of dials in Rome. According to this fragment, the city was already *opleta solariis*, full of sundials. However exaggerated, to make its effect, the remark has to be grounded in reality. When Plautus addresses his audience, he expects them all to know what a sundial is, what it is used for, and where it is to be found. All this presupposes a well-established assimilation of the instrument, effective at least from the third quarter of the third century BCE, which more or less coincides with the date of 293 BCE advanced by Pliny.

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[34] *Hist. Nat.,* vii, 212–15.

[35] Varro, *The Latin Language*, vi. 4.

[36] Savoie 2007, 1170–5; Savoie 2014a, 21–7.

[37] Catania has a latitude of 37° 30′; Rome 41° 54′.

[38] Savoie 2007, 1172.

[39] Veyne 2005, 196.

[40] This story of the dial seems risible compared with other, far more embarrassing, Roman errors. For example, the civil calendar was in advance of the astronomical data by some four months at the end of 190 BCE, March falling in October. This should have been an evident problem, not the imperceptible displacement of a few minutes on a sundial.

[41] Aulus Gellius, *The Attic Nights*, iii, 3. 4–5.

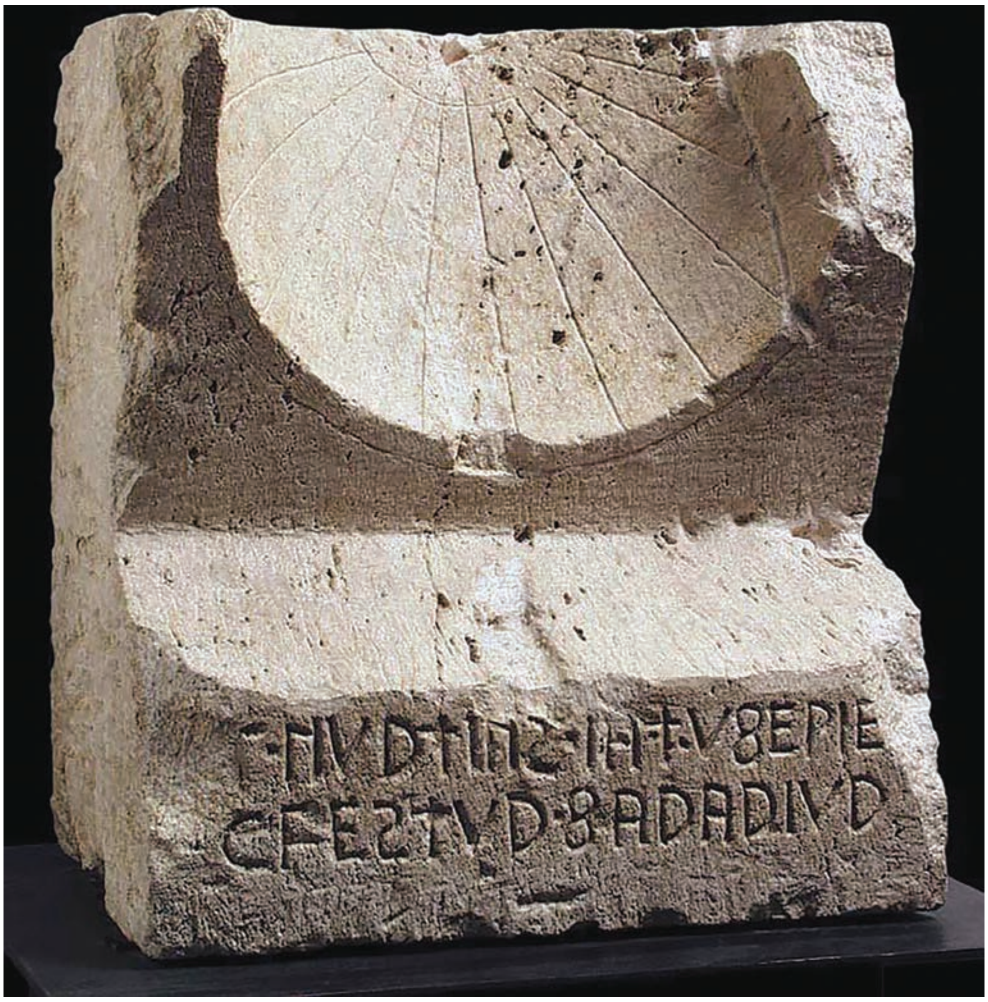

Figure 4 Inscription and dial. Image created by Jérôme Bonnin based on the dial from Bevagna (Museo Archeologico Nazionale, Perugia, inv. 50,028.

Archaeological sources do not go back so far. The oldest known sundial comes not from Rome, but from Bevagna, a town in modern Umbria.[42] It is a spherical dial, without declination curves, mortised into its base (Figure 4). This suggests that it was mounted high, probably on a column. It measures 43cm in height by 40cm by 26cm. The base carries an inscription in Umbrian written in Etruscan characters recording that it was the gift of Norinus and Iantus Aufidius *quaestores fararii* (food magistrates). Following this inscription the dial has been dated to between 263 and 190 BCE[43] using as criteria the disappearance of Etruscan characters for Umbrian after 190 BCE. This in no way contradicts the texts of Pliny or Vitruvius, nor any known archaeological findings. The Romanization of Umbria began from the 290s BCE onwards. Therefore, it is likely to find a dial at the end of the third century BCE. Dials were already present in Rome at this period, and they would spread more and more quickly in the cities that came under Roman control.

It was indeed exactly at this time that timepieces became a social necessity and were no longer the province of a few savants. Briefly put, the Greeks, inheriting Babylonian knowledge in astronomy, and rather less from the Egyptians, developed increasingly complex instruments. Used first strictly in a scientific context in the sixth and fifth centuries BCE for studying the sky and its apparent movements, they slowly left this restricted area and became used by political authorities. In the fourth century BCE dials and water clocks expanded into the major cities, becoming indispensable for some people, although still objects of curiosity for others. This technology was introduced into Rome towards the middle of the third century BCE and little by little spread through the region around the city. By contrast with what occurred in Greece, the sundial had a hitherto unprecedented development in the Roman world—opposite to that of the water clock. To understand this fully, and to correct some persistent errors about Roman timepieces, it is first necessary, after having defined the term *horologium* precisely, to present the characteristics of the archaeological pieces in detail.

HOROLOGIUM: A DECEPTIVE TERM

As David Landes (1924–2013) noted as regards the Middle Ages,[44] the word *horologium* is ambiguous, and does not allow us to know

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[42] Concerning this dial, see Ciotti 191, 81–5 and Bonnin 2015, A-46.

[43] Filippetti 2000, 64.

[44] Landes 1983/2000: ' . . . it is one of the misfortunes of scholarship that there was only one word for clock in the western Europe of the Middle Ages: *(h)orologium*. This generic term referred to every kind of timekeeper, from sundial to clepsydra to fire clock to mechanical clock. So, when in the late thirteenth century, we get an unprecedented spate

exactly what kind of object is referred to in an ancient text. The Romans themselves did not fail to note this ambiguous, generalizing aspect of the term. However, by contrast, there did not exist in Antiquity a single term in either Latin or in Greek.

In Greek a water clock, like a sundial, is called ὡρολόγιον. In literary texts this can be replaced by ὕδριον ὡροσκοπεῖον.[45] Generally it is completed by a composite term using the word ‘water’, either by the addition of a qualifier or by a periphrasis. This linguistic procedure is found in Lucian (120–180 CE)[46] when he mentions the clock of Hippias, which had two devices for showing the time: ‘one by means of water and roaring, the other displaying it by means of the Sun’: references to the Sun and water are classic for designating sundials and water clocks. ‘Roaring’ refers to a compressed air system that indicated the passing hours. In literary texts a somewhat perturbing use of ‘clepsydra’ is found. But the difference between the water clock and the clepsydra is distinct: two instruments of different usage are concerned. Even so, since the clepsydra probably lies at the origin of water clocks, some authors in Antiquity occasionally used the term ‘clepsydra’ in a loose or ambiguous way. It should not, however, be thought that ‘clepsydra’, at least before Late Antiquity, could be a synonym for water clock. Ancient authors were far more aware of the difference than modern authors,[47] who still, unfortunately, use ‘clepsydra’ for ‘water clock’, and *vice versa*. Different generic terms also exist in Greek to name the various types of sundial. As for the water clock, the commonest is ὡρολόγιον or ὡρολογεῖον. These are followed by an equally widely used term, ὡροσκόπιον or ὡροσκοπεῖον (literally ‘watcher of the hours’), which always indicates a sundial in general of no particular type.[48] The terms ἡελιοτρόπιον or σκιαθηρτκόν are much rarer and apparently designate particular instruments of the oldest kind (discussed earlier). They are found almost exclusively in the early texts and are very rarely used for sundials.

In Latin, *horologium*, calqued on the Greek, is also generic. It is the term most commonly used in epigraphs (78% of recorded inscriptions) and in literary works. As in Greek it serves indifferently for sundials and water clocks. Vitruvius (*c.*90–*c.*20 BCE)[49] has to add *ex aqua* to specify the kind of instrument of which he treats (*horologiis ex aqua*), although only at the beginning of the chapter, the context sufficing thereafter to make his meaning clear. In the sixth century CE, Cassiodorus (*c.*485/90–*c.*580/5 CE) still uses qualifiers to differentiate the two kinds of timepiece.[50] Other terms however were used such as *solarium*, a term specific to the Romans. Initially it designated a sundial but, little by little became applied to water clocks when they showed the day hours. Censorinus (3rd century CE), among other authors, uses *solarium* for the sundial, and *horarium* for the water clock, while explaining that the latter takes the name of *solarium* when it shows the hours of the day:

> P. Cornelius Nasica made a time-piece (*horologium*) functioning with water, which is also called a *solarium* from the name of the Sun, which makes the hours known.[51]

Finally, therefore, by a displacement of sense, *solarium* (a word initially reserved for sun-based timepieces) came to mean either sundial or water clock. Censorinus’ explanation is the more interesting since water clocks would also be calculated and regulated by sundials.

So what is to be understood, in terms of objects, when speaking of water clocks or sundials in Graeco-Roman Antiquity? The former are presented first as they constitute only three per cent of the archaeological corpus but, unlike sundials, have a very substantial bibliography because they have often been studied during the nineteenth and mid-twentieth centuries.[52]

Water clocks

In the first place, the *clepsydra* is an object that cannot be included in the class of instruments allowing time to be read (*horologia*). Although no ancient author confused the two instruments, many modern commentators use the terms interchangeably, as if they were synonyms, which is not the case. In modern terms the clepsydra differs from a water clock only by its use. It does not

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of references to clocks, we cannot be sure *prima facie* what kind of device our sources are talking about’.

[45] For example, in Hero of Alexandria *Pneumatica*, i, 1: ‘We have moreover been led to write about this subject since we found it a natural extension of our treatise in four books about water clocks’.

[46] *Hippias or the Baths*, viii.

[47] It was certainly modern authors who introduced errors and found problems that did not exist. For example, in his 1684 translation Claude Perrault was astonished that ‘Vitruvius, who so affects bringing in Greek names to signify things that have Latin ones, employs here a Latin circumlocution instead of using the term clepsydra, use of which was very common among the Romans’. In fact, Vitruvius knew very well that neither in Greek nor Latin did clepsydra designate water clocks.

[48] This term is found in scientific literature notably in Geminos (*Introduction to the Phénomena*, ii, 35 and xvi, 13) and Strabo (*Géography*, ii, 5, 14: τα ὡροσκοπεια). It is also used by Diogenes Laertius (*On the Lives and Opinions of the Philosophers*, ii, 1) and in epigraphs showing clearly that the word refers to sundials.

[49] *De Architectura*, ix, viii.

[50] Cassiodorus *Institutiones*, i. 30.5. ‘This is why I have prepared for you a timepiece that goes by the light of the Sun; and another that indicates, day and night without stopping, the number of the hours’.

[51] Censorinus, *Of the Natal Day*, xxiii.

[52] For technical and mechanical details, proposed reconstructions, and the automata and other ornaments mentioned directly or indirectly in the texts, reference can be made to older but fundamental works with numerous references to the writers of Antiquity. Blümmer 1875–88; Beck 1899; Neuburger 1919. Diels 1917, although its reconstitutions of water clocks contain many errors, remains valuable. Essential information is also presented in Kubitscek 1928; Meerwaldt 1921; Beaujeu 1948; Drachmann 1948; Price 1975; Turner 1984b, 1–9; Nordon 1991, 83–91; Turner 1994, ch. 1; Lewis 2009; Turner 2000; Hannah 2008. For automata, see Hill 1976; Hammerstein 1986.

indicate the hour but measures a discrete interval of time. It is a 'timer', and cannot function continually, but, like a sand-glass, is set in motion at a specific moment, stops after the predetermined period built into it, and has to be restarted when needed. In Ancient times, this system of stop and restart became an integral part of law court procedure, and the expression 'stop the water' is very familiar in Greek texts. For example:

> After having delayed paying the sum adjudicated, he at last paid after an accommodation with the adversary. I can produce witnesses to this effect. Clerk **stop the water** and bring in the witnesses.... Before he could know about this arrangement he fled from here for fear of Aristodikos and settled in Thebes. Now, you know, I think that, had he been a Plataean, it is probable that he would have settled anywhere else other than in this town. I shall produce witnesses to show that he had lived in Thebes for a long time. Clerk **stop the water** and bring in the witnesses.[53]

Examples of this kind abound. This use continued in Rome and has left its trace in Latin texts. The 'timer' function was essential and in writings of the Roman period *clepsydra* is well attested, most of the time being used in its correct limited sense.

It is rather difficult to confuse a clepsydra with a large water clock. The former, according to a passage in Athenaeus,[54] can be traced as far back as Plato (428–348 BCE), and their development is marked by other great names such as Ctesibios of Alexandria (3rd century BCE), Archimedes (287–12 BCE), Philo of Byzantium (3rd century BCE), and later, after Vitruvius, Hero of Alexandria (1st century CE). Vitruvius, our main source concerning Roman water clocks, offers a synthesis of the different types of structures known, 'the same authors also sought a way to realise timepieces through the use of water'.[55]

Vitruvius gives copious technical information. Firstly, by his training, he was often in contact with such machines, which had become essential in the military world. He knew them well, could have used them, and have helped in their construction, or simply had the time to examine them and understand the way they worked. Thereafter, 'he sought equally to make them known and understood, in a word, to educate his reader'.[56] The first device described should be classed, according to Vitruvius, in the category 'amusements'. This was the water clock invented or, more probably, improved by Ctesibios of Alexandria. His first innovation was to form the outlet hole (at the base of the clock) in a piece of gold or a gemstone. Choosing gold, perhaps for its precious and inalterable nature, was not without drawbacks, given its soft, deformable character. Moreover, despite Vitruvius' belief to the contrary, it did not hinder the deposit of impurities. The second innovation was to replace the internal hour scale, which was difficult to read, with a more convenient external one. This was accomplished by the addition of a *scaphium inversum*: a cork, wood, or ceramic float in the form of an inverted bowl filled with air[57] and placed in the lower vessel. In its simplest form the instrument functioned as follows: the float carried a vertical rod surmounted by a figure that indicated the hours with a pointer on a structure (a pillar or column) placed beside the clock carrying an hour scale that was changed each day.

Following this, Vitruvius describes two different methods for reading the hour. The first is a clock with a fixed graduation in which the length of the unequal hour is simulated by varying the outflow rate. The explanations of this are abundant but difficult to follow, and at times he seems to doubt the efficacy of these regulating systems. The second method employs a constant water outflow, where the graduated pillar is replaced by a column on which the hours are shown by curves drawn 'after the analemma', a graphic realization of the variation of the unequal hours throughout the year. The column needs to be turned each day so that the pointer is set on the line for the day and month of use. No mechanism for doing this is indicated, but the column can easily be manually turned. Finally, Vitruvius tells us, other mechanisms gave aural indications and moved automata, all this in the great tradition of Alexandria, which would continue until at least the sixth CE and which Arabic engineers would pursue still further. But had Vitruvius actually seen these automata, or did he take the description of them from the *Commentarii* of Ctesibios? He only mentions them, without explanations, despite the fact that they are complex devices apt to astound.

Finally, Vitruvius describes an instrument that he seems to have seen working and for which archaeological evidence is available to help reconstruct it. This is the anaphoric clock, also known as the *horologia hiberna* (winter clock).[58] In winter, human activity continues after sunset, which justifies the use of such devices. It is generally agreed by contemporary authors that such clocks showed the rise and set of stars, a hypothesis supported by the Greek term which, for astronomers signified 'the rising of a star'. Realizing such a clock, however, is complex, as is the description given by Vitruvius.

The dial of an anaphoric clock is composed of a metal grid (*virgulis aeneis*) through which a mobile disc placed behind it can be seen. The stationary grid is composed, according to Vitruvius, of twenty-four separate hour lines curving from the centre to the circumference and of seven concentric circles representing the months grouped in pairs except for June and December. Behind the grid, the vertical disc, carried on a horizontal arbor turned by a counterweight, shows the constellations, the ecliptic, and the signs of the zodiac. In such clocks it is the position of the degree of the ecliptic corresponding with the date that indicates the hour as it moves behind the fixed metal grid. In

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[53] Lysias, *Against Panelion*, xxiii, 14–15.

[54] *Deipnosophists*, iv. 174b.

[55] *De Architectura*, ix, 8–2.

[56] Fleury 1994, 205

[57] Bilfinger 1886, 42; Ardaillon 1900, 262. The Greek synonym given by Vitruvius, *phellos*, meaning 'oak cork' suggests that the first floats were worked in cork, to be replaced later by others in wood or ceramics.

[58] On this type of clock, see especially Turner 2000.

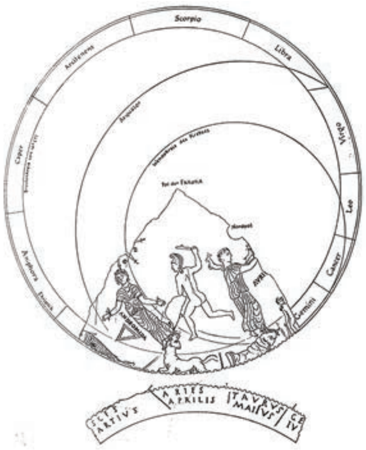

Figure 5 Reconstruction of the dial of the Salzburg anaphoric clock. By Jérôme Bonnin, after Kuenzel 2000, 548.

addition, the ecliptic circle is pierced with small holes, each one corresponding with a day of the year. A bright indicator was set manually in the hole for the appropriate date and was sometimes furnished with an index. The latter offered the advantage that it allowed the indicator to be more easily distinguished behind the hour grid and facilitated manipulating it. It is for this reason that the remnant of such a clock, found at Salzburg (Figure 5), carries the names of the months on the reverse of the disc to guide its keeper in resetting it each day. It was this that supplied confirmation of the nature of this fragment as part of an anaphoric clock.[59]

Found in 1901, the Salzburg clock is composed of part of a bronze plaque originally of about 1.2m in diameter and two millimetres thick. On one side a fracture follows the circular path of a series of small holes which can be identified without difficulty as the *cava*, which Vitruvius tells us were set in the ecliptic. No doubt a public clock, it would have been particularly impressive and prized. The mechanism and the decoration around would together have taken up a considerable amount of space; it was perhaps housed in its own protective shelter. Knowledge of it allows the accuracy of Vitruvius' account to be gauged.

A second instrument of the same type was found in 1886 at Grand (Vosges, France), a well-known Roman thermal station.[60] It consists of a fragment of bronze similar to that of the fragment from Strasbourg except that it is smaller and has no zodiacal indications. A piece of bronze that would originally have been part of a disc of 35cm diameter recovered in 2008 on the military site of Vindolanda (on Hadrian's Wall, England), was initially thought to be part of an anaphoric clock or a parapegma.[61] It has perforations and shows the names of the months (only September survives), abbreviations for the Kalends, Nones, and Ides, and indications for the equinox. It comes from a ring of bronze that supplied the outer, upper, edge of a hemispherical outflow water clock, the holes being probably to receive a marker to indicate which scales on the interior of the vessel were to be used for the time of year. It is similar to the rim of a complete clock held by the Frankfurt Archaeological Museum since 2000.[62] If the Vindolanda find-site suggests a military purpose for the instrument, serving perhaps to fix the times of the watches or other administrative formalities such as the arrival and the despatch of messages, other evidence, including a further such fragment found on the rural site of Hambledon, Hampshire (England), suggest that the use of simple water clocks was widespread. That is, their use was not confined to any specific task despite some strong evidence that enables them to be associated with the control of hours for male and female frequentation of public baths.[63]

Sundials

It is not usually difficult to recognize an ancient sundial. They adhere to a general schema that is fairly simple whether in terms of the material used, their shape, or their constitutive elements. Rather few materials are used: only local or imported stone and the metal pieces needed to make them function. Less essential, decoration is sometimes added, such as stucco or coloured pigments. Marble, followed by limestone or local stone, is the most common material. Portable dials are generally made of bronze or a similar metal alloy, but examples in bone also occur. The gnomon was usually made of bronze but there exist some rare examples in iron. Whatever the case, it was always anchored in place with lead, and many dials retain traces of this. Occasionally the negative imprint of a prismatic gnomon is still clearly visible, as are traces of the tool used to drive out the air and allow the gnomon to be perfectly adjusted to the lead and the stone.[64] Additional material can enhance (or camouflage if poorly executed) the quality of the instrument. This is notably the case of stucco used to cover stone of little aesthetic appeal, such as tuff and some calcareous stones. Its absence may be the result of erosion or of pieces being abandoned. Finally, some rare survivals show that the hour and declination lines could be highlighted with black or red pigment; this was probably generally the case, not an exception. But dials made of tuff, covered with stucco, and painted are fragile. It is difficult to imagine that they were placed in the open air. Perhaps they were placed on the edge of the peristyles of the *domus* or more modest dwellings, or they were protected from rain by a light structure that did not hinder the passage of sunrays when reading

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[59] Kuenzel 2000, 548; Rehm & Weiss 1903, 33–41 & 41–9, figs. 18–22.

[60] Maxe-Werly 1887, 170–8; Nordon 1990, 27–42; & fig. 8, Turner 2000, 540–2. It is conserved in the Musée des Antiquités Nationales, St Germain-en-Laye.

[61] Lewis 2009, 13–17.

[62] Stutzinger 2001; Meyer 2019.

[63] Meyer 2019, 194–9; for the hours and the baths, see Bonnin 2015, 229–34.

[64] So the gnomon of a conical dial preserved at Athens in the reserves of the Museum of the Stoa of Attalos (inv ST. 147). *Cf.* Gibbs 1976, 230.

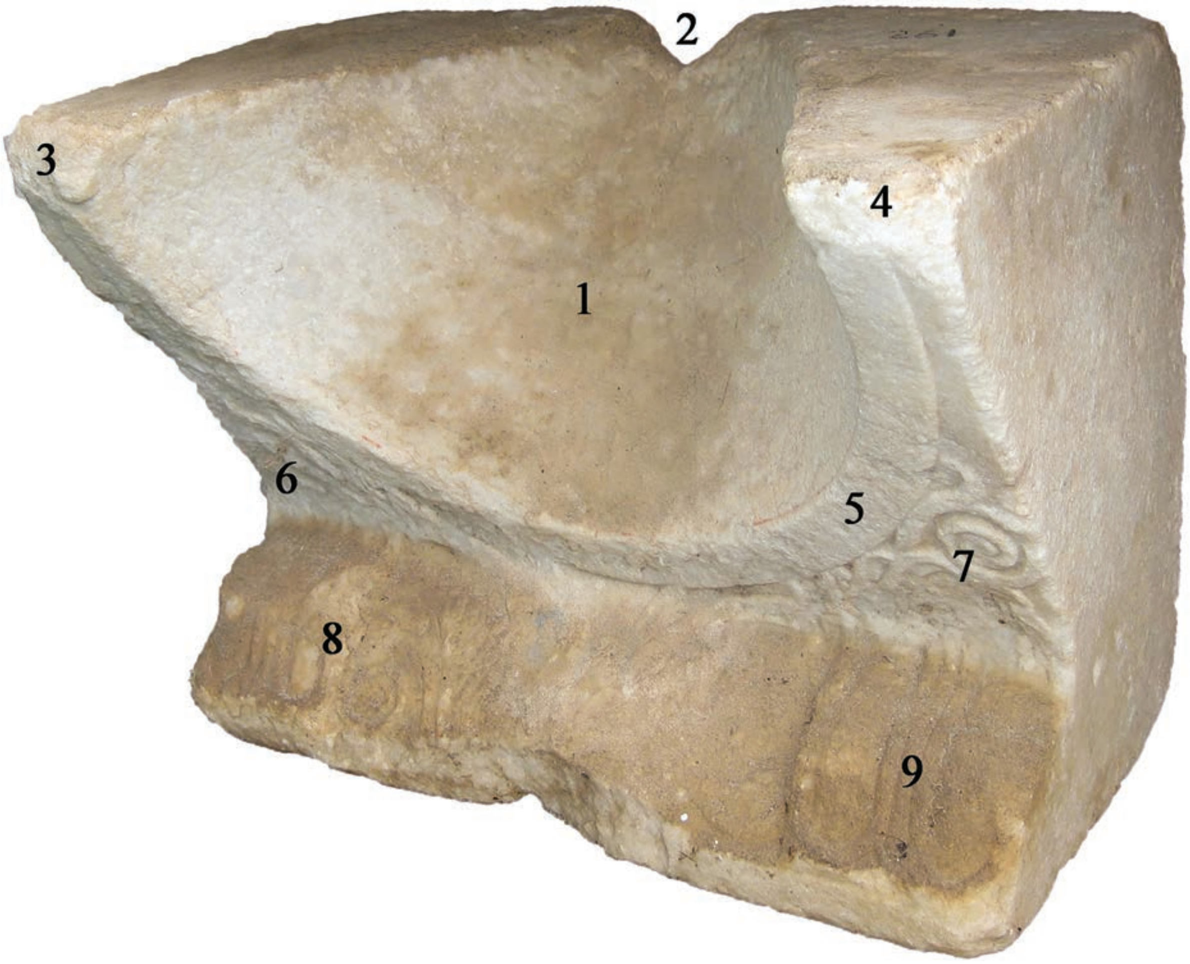

Figure 6 Constituent parts of a standard sundial (Delos, inv 261). Photo J. Bonnin.

the hour. Many vertical dials today are placed beneath the gutters or eaves of buildings, thus protecting them without hindrance to their functioning. This remark applies specifically to private dials; public ones were generally of a far better quality. For this reason many of them could be mounted on columns or in high positions, easily visible for all. It was probably the same for dials placed in the necropols, where vertical plane **dihedrons** and spherical dials with **aperture-gnomons** preponderate. These forms rendered the stone less liable to water damage.

Sundials formed from a hollowed block (conical, spherical, spherical with **aperture gnomon**, cylindrical, or multiple) are composed from various typical elements that are found in the majority of examples. This is also true, though in a minor degree, of dials drawn on plane surfaces. In the majority of cases they have two distinct sections—the base, and the receiving surface—and usually seven fixed parts (Figure 6).

The part that receives light is composed of (1) the receiving surface itself, (2) the **gnomon** or its position when the **gnomon** itself has disappeared, (3) the left extremity, (4) the right extremity. This upper part of the dial is sometimes separated from the base by (5) a moulding. Between the base and this moulding shaped corner-pieces (6) and (7) carry figurative or non-figurative decoration. Finally, the base is usually flanked with two feet of variable form (8) and (9).

The hour lines, usually eleven in number, divide the receiving surface into twelve equal parts.[65] They are frequently complemented by **declination** curves, usually three in number. In this case the equinoctial line is always at the centre of the instrument. The curve representing the summer solstice line is found farther away from the base of the gnomon on surfaces cut into a block or on plane vertical dials, and closer in plane horizontal dials. The opposite is true for the winter solstice line.

Up to now, archaeological investigations have brought over 650 different dials to light. The difficulty for the historian is to find a correspondence between them and the typology derived from the ancient sources—Vitruvius in particular. The details of ancient dials and how a particular form can be attributed to a particular

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[65] Six dials show either too few (9 or 10), or too many (12 or 13) hour lines. These are late dials no longer using the classic hour system or, for those with thirteen lines, a desire to represent the first and the twelfth hours by separate lines. For dials with too many lines, see Gibbs 1976, 168 (1054G from Durostorum); Bonnin 2012, fiche A_449 (unpublished sundial from Masada). For dials with too few lines, see Gibbs 1976, 359 (5018 from Akrai); Bonnin 2015 395, A_337 (dial from Richborough); Bonnin 2012, fiche A_511 (dial from Ville-Pommeroeul); Schaldach 2006, 126 (dial from Isthmia).

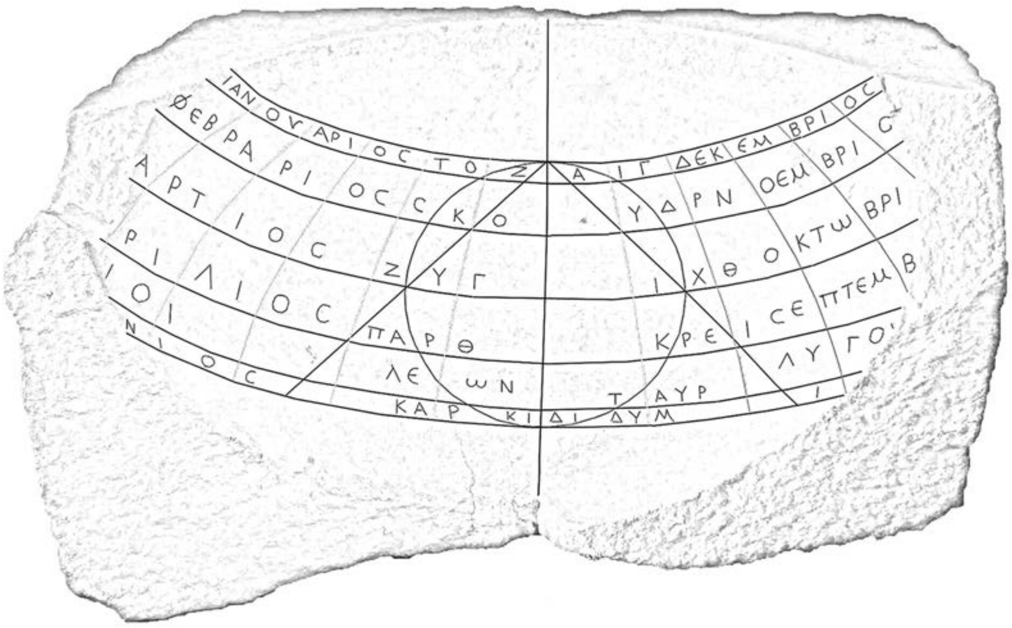

Diagram 1 Hemispherical dial.

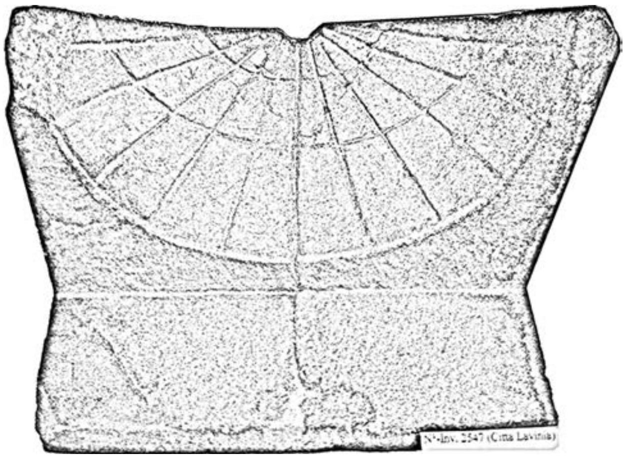

Diagram 2 Quarter-spherical dial.

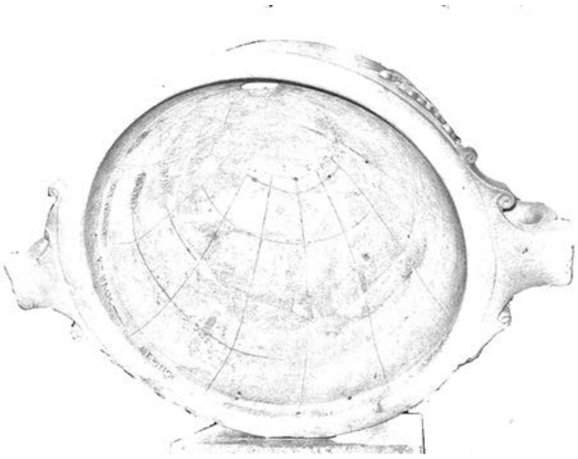

Diagram 3 Spherical dial with aperture gnomon.

name are discussed elsewhere.[66] Briefly, however, fifteen types of dials are known from archaeological sources.

Hemispherical dials As the name indicates these dials (Diagram 1) have a hemispherical receiving surface (not a quarter sphere). If not *the* oldest form, it is certainly one of the earliest to have been developed.

Quarter-spherical dials Spherical dials have a receiving surface that forms a quarter sphere (Diagram 2). Although one of the commoner types, few of the many surviving specimens are accurately executed.

Spherical dials with aperture gnomon This type is characterized by an inclined, half-spherical receiving surface that corresponds with the latitude of the place where it is erected (Diagram 3). It is fitted with a zenital aperture gnomon. The hour grid is complex and difficult to execute. When it has survived, the upper part of the instrument may still retain traces of the seat of the circular pierced bronze plaque that formed the **aperture gnomon** fitted with metal pins anchored in lead.

Conical dials With its dial surface formed from the trunk of a cone (Diagram 4), the lines on these dials are shallow curves and thus easier to draw than those for a spherical dial. As a result this is the commonest of surviving dials.

Conical dial with aperture gnomon Only two examples of this type are known. Made in the same way as a spherical dial with aperture gnomon but with a conical receiving surface, the gnomon is replaced by an orifice placed at the supposed extremity of a bar (Diagram 5). Technically complex, it is unlikely that many dials of this sort were ever constructed.

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[66] See Bonnin 2015, 98–126.

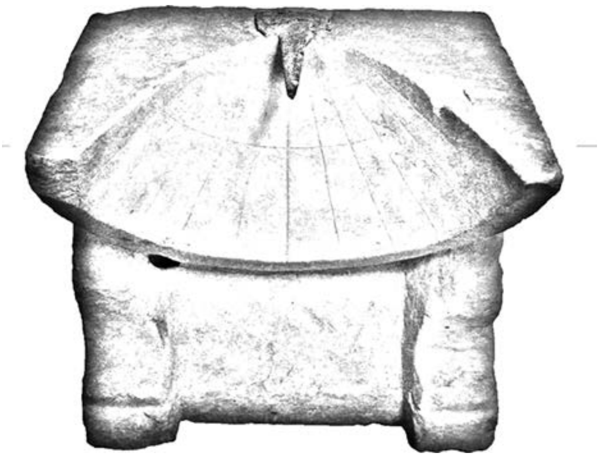

Diagram 4 Conical dial.

Diagram 5 Conical dial with aperture gnomon.

Inclined cylindrical dial Although only one example of this category is known, it is indisputably a separate type. The sole example comes from Aï Khanoun, a city founded by the Greeks in the fourth century BCE. It is composed of a parallel-sided block with a large circular opening at the centre (Diagram 6). The bloc is inclined appropriately for the latitude. The hour lines are drawn on the inner, lower surface of the cylinder formed by the central opening. The **gnomon**, in the form of an inverted 'T', is set in the top of the cylinder and shows the hour on the two lower edges of the cylinder according to the season. An illustration of the high degree of mathematical and astronomical knowledge attained by the Greeks, it was probably abandoned for simpler instruments. It should be noted, however, that this unique example, although correctly inclined for the latitude of Aï Khanoum, does not have hour lines correctly drawn for this location.[67]

Spherical dials Two dials only, both indisputable technical masterpieces, are known of this kind. The general form is very simple. The dial is drawn on a solid sphere (Diagram 7). The hour is read thanks to a shadow line (a terminator), created by the sphere on itself.

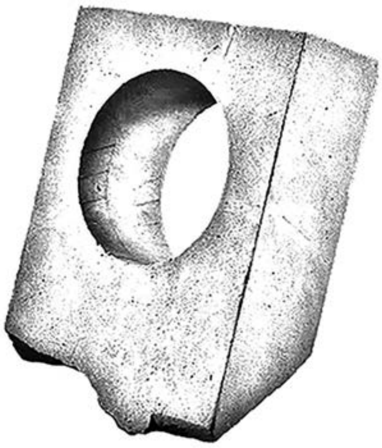

Diagram 6 Inclined cylindrical dial.

Diagram 7 Spherical dial.

Plain horizontal dials The dial face is a horizontal slab on which the hour line grid takes the form of a butterfly with outspread wings or a double headed axe (Diagram 8). What matters in this group is not the nature of the support, the size, or the geometric characteristics, but rather the form of the receiving surface.

Vertical plane dials The dial face is set in the vertical plane, usually south facing, and carries an hour grid composed of twelve sectors (Diagram 9). It is these 'protractor' dials[68] that seem to be the origin of the similar dials and 'mass' dials found throughout Europe during the Middle Ages. They are neither very elaborate nor particularly well made. Some seem more to be preliminary layouts for a dial rather than true scientific or everyday instruments. The only real public dial of this class is found on the Tower of the Winds in Athens, but this deploys a quite different hour diagram.[69]

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[67] See Savoie 2007.

[68] Term from Gibbs 1976, 46.

[69] For a presentation of this emblematic monument of ancient horology see Figure 7.

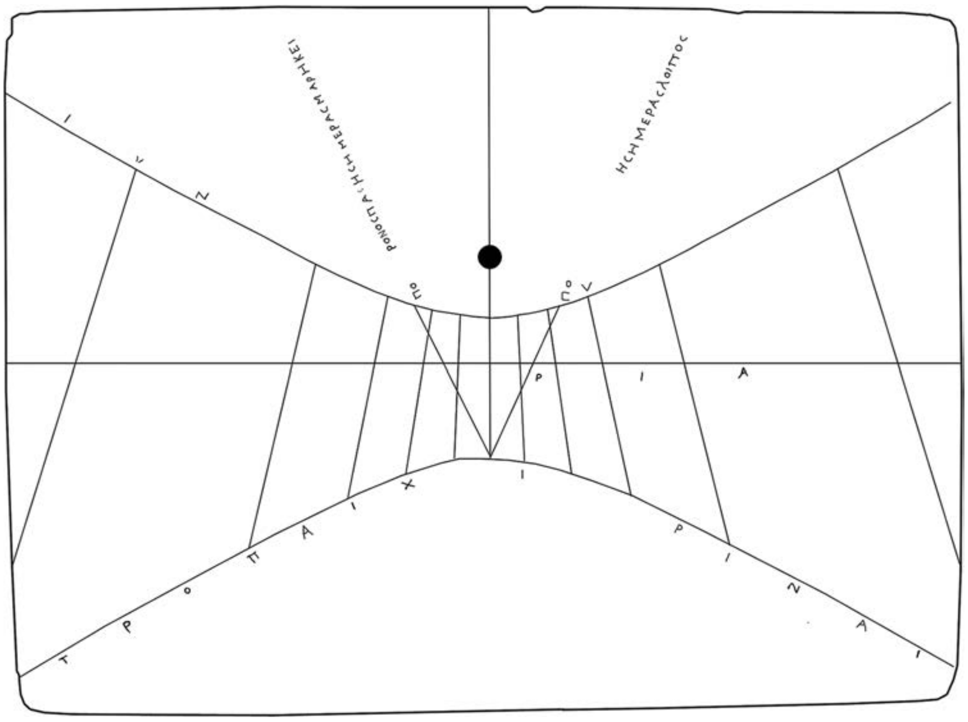

Diagram 8 Plain horizontal dial.

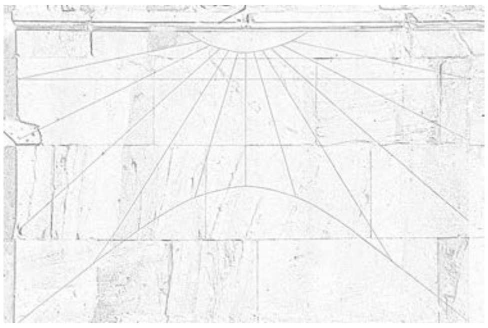

Diagram 9 Vertical plane dial.

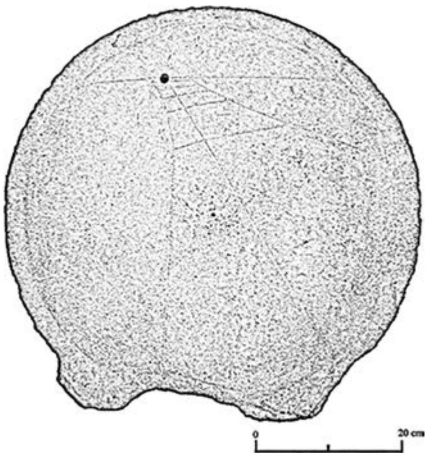

Diagram 10 Circular plane vertical declining dial.

Declining plane vertical dials This group of dials are known as 'declining' because they do not face due south. Rather, they 'decline' away from it towards the east or west and the form of the hour diagram changes although this is always composed of six sectors.

Circular plane vertical declining dial Known from only two examples, dials of this group are formed of a circular stone disc with parallel faces set vertically on a base (Diagram 10). Each face carries a direct east- (morning) or west- (afternoon) facing hour grid. The edge of the disc may also carry a **meridian** line with its own **gnomon** since such dials do not allow a time-reading close to midday.

Plane dial, inclined Once again, only two examples of this kind of dial are known. It consists of a narrow stone plate with two dial faces, one for summer, the other for winter. The entire instrument is set in position inclined at an angle corresponding with the latitude of the place of use. The form of the hour grid resembles that of plane vertical dials.

Multiple face dials Dials in this group have no specific characteristics except in possessing several separate receiving surfaces (Diagram 11). The twenty-two known examples, all different, are among the most astonishing products of ancient dialling.

Plane vertical dihedral dials These dials are formed of two narrow stone plates usually set at right angles to each other (Diagram 12) on a base (in most cases now missing). The gnomon, of prismatic or extended cylindrical form, is found at the intersection of the two plates, fixed with several mortises and sealed in with lead.

Portable dials Easily transportable because of their small size (Diagram 13), and rapidly prepared for use, portable dials fit uneasily into a single category since many of them are *sui generis*.

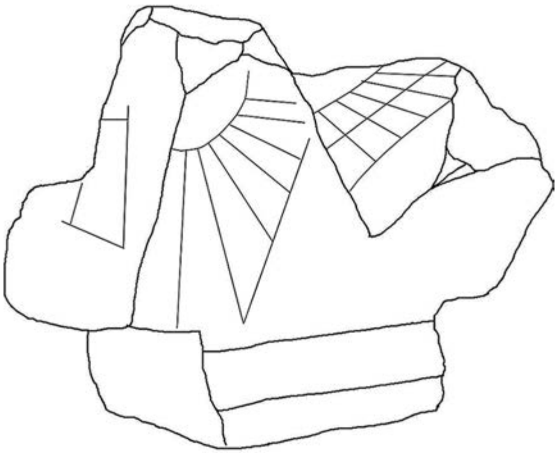

Diagram 11 Multiple face dial.

They are currently the subject of much revision, with an increasing number of studies of them and with new discoveries (or rediscoveries) enlarging the corpus.[70]

Precision

The diversity of forms and technical possibilities sketched above is, in itself, evidence of the interest shown by Greeks and Romans in time measurement and its instruments. This was such that *horologia*, sundials, or water clocks, became omnipresent in civic life, this gradually effacing their earlier scientific, astronomical, use. In the third century CE, and for almost everyone after Cetius Faventinus (3rd century CE), the sundial is no more than a means 'to know time in the quickest way'.[71] From this affirmation it can be understood that often the accuracy of the dial mattered little if it allowed this need to be satisfied. This impression can be corroborated from archaeological sources. The study of the 'precision' of ancient dials reveals much about the role assigned to them, or at least about those that are the most frequently encountered.[72] However, it is necessary to understand and to accept the limits. Many modern studies have pushed the results available too far, mathematically overinterpreting them.

The Greeks, and even more the Romans, did not share our modern demand for precision to the last minute. Indeed, such a conception is completely anachronistic. An error of five to ten minutes, in modern terms, was of little importance; approximate time was the norm. These five or ten minutes of difference from 'real time' could only be perceived with difficulty since no standards existed by which to compare measurements. Moreover, if craftsmen, often of Greek origin, were perfectly capable of producing reliable, well-calculated instruments, perhaps few people used the declination curves on dials to locate themselves in the year. To rely on a dial for calendrical ends would have been the source of many errors. But since dials in origin were prestigious astronomical instruments that offered complicated information to those who knew how to use them, they retained these attributes for a long time. Their signification was rather symbolic than astronomical, or even pedagogic. Eventually, the dial surface of everyday instruments came to be used uniquely for reading the hour. In the light of this, we can better understand why Cetius Faventinus cuts short his explanations of the most complex dials, insinuating that they interested no one, particularly not the wealthy land owners to whom his manual was addressed. It is also easier to understand why Vitruvius cites extremely rapidly the kinds of instruments known and their characteristics. A sundial should serve to locate oneself in the day and all 'furniture' was to be excluded.[73] Finally, it should always be remembered that the notion of an exact and constant hour did not exist; when someone asked the time, he was reassured to have several replies,[74] as Seneca implies:

> I think you will understand better if I tell you that we were in the month of October, and at the third day of the Ides of October. I cannot tell you the hour exactly. Philosophers can be made to agree more easily than timepieces. Even so, it was between the sixth and the seventh.

This passage does not prove that all the timepieces at Rome were of poor quality. It simply attests to their variable quality. One instrument necessarily differed from another as they were individual artisanal works lacking uniformity or a single conceptual approach. And even on two identical instruments, the reading would be different for different observers because, unless the gnomon-shadow fell exactly on an hour line, the reading was always approximate, there being no intermediary graduations.[75] This can become habitual, as with modern watches without numerals, although the reading is less precise. But it was of little importance. A Greek or Roman having a meeting at the third hour did not regard the dial as we do. He simply organized himself not to arrive too early or too late.

MAKERS AND METHODS

There are few elements that allow us to reconstruct how an Ancient sundial was created. If some hypotheses can be advanced for spherical, conical, or plane dials, for others, notably the portable dials, it is difficult. Ancient authors furnish almost no really useful information on the subject. The text of Cetius Faventinus is symptomatic of the problem. He does not tell us who realized the devices, nor what was the manufacturing chain.

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[70] See Arnaldi & Schaldach 1997; Savoie & Goutaudier 2012; Hoët-Van Cauwenberghe 2010b; Talbert 2017; Talbert 2019.

[71] Cetius Faventinus, xxix.

[72] On this subject, see in particular Savoie 2014a, 17–32.

[73] By contrast, Vitruvius devotes several pages to water clocks the reading of which was more complex and which, probably because of their cost, combined several uses in order to justify this to their users.

[74] Carcopino 1939, 189.

[75] Except on some extremely rare dials, where the half hour is marked.

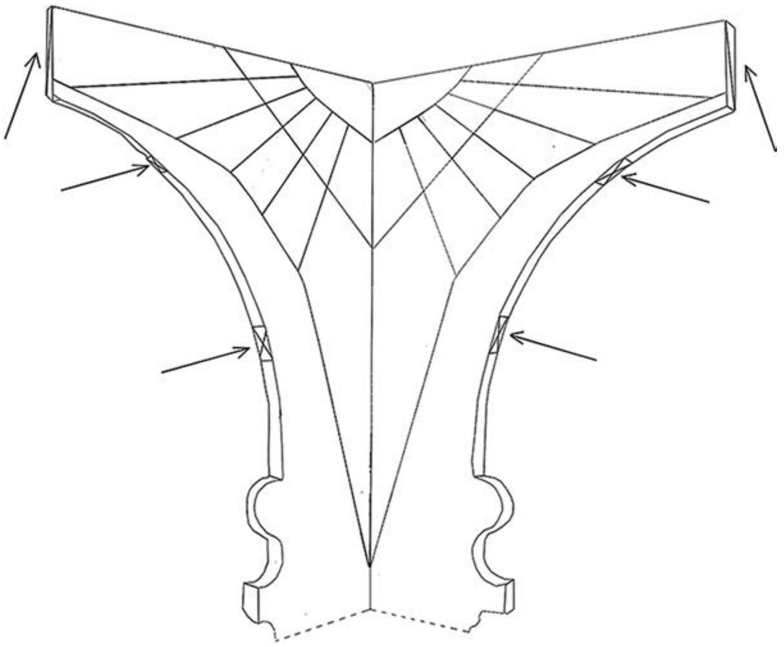

Diagram 12 Plane vertical dihedral dial.

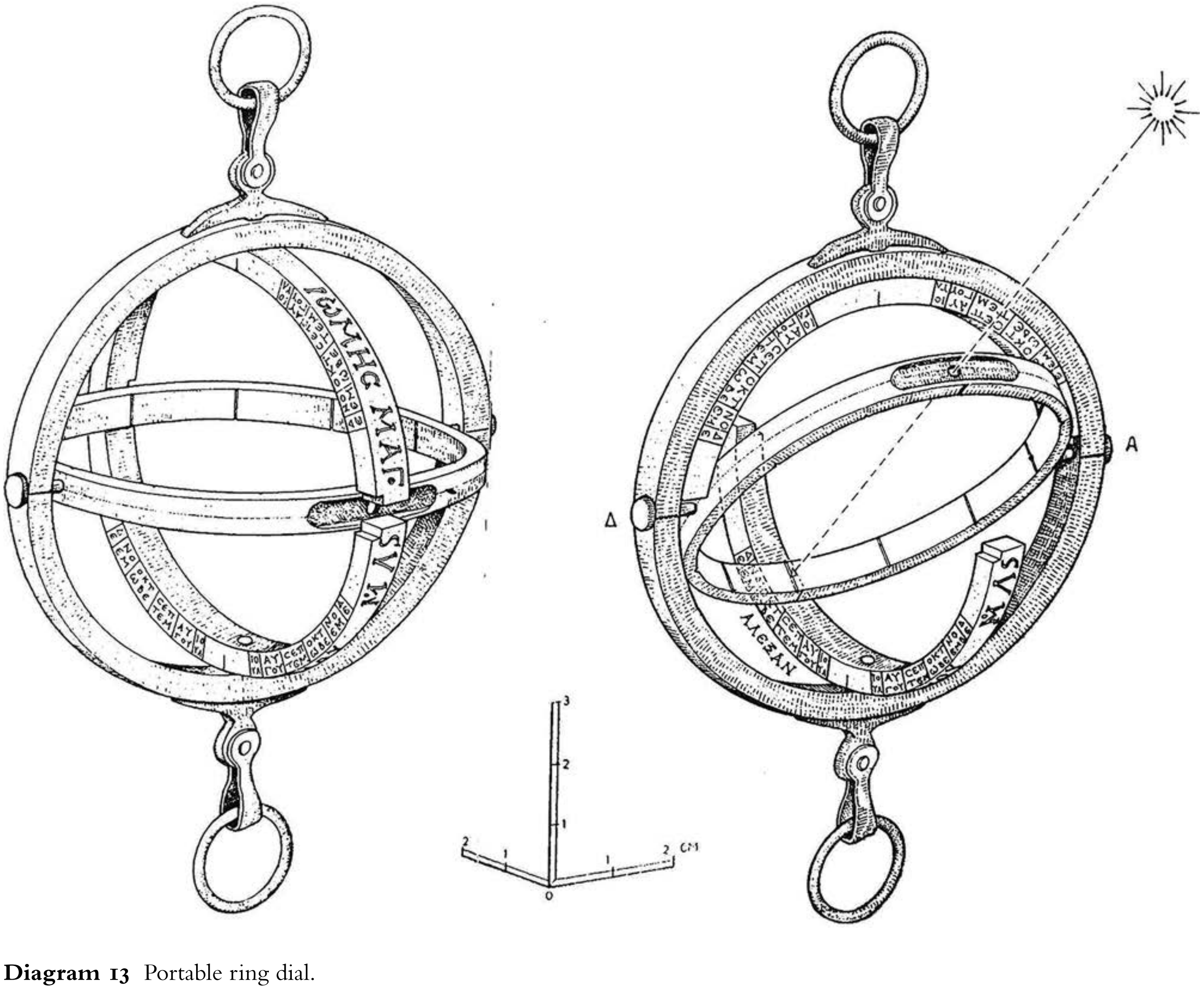

Diagram 13 Portable ring dial.

For the *pelecinium* dial, albeit in simplistic terms, he attempts to show the progression from 'two plaques of stone, larger at the top, narrower at the bottom' to a finished dial. But what he describes cannot lead to a finished dial and his 'method' seems rather imaginary than otherwise. If the main steps are exact (shaping of the plaques, drawing the lines, installation of the gnomon), details are either non-existent or wrong. When Cetius Faventinus discusses the spherical dial with aperture gnomon he gives no indication of how to draw the declination curves. It is the same for the hour lines 'drawn as eleven, equally spaced, straight lines to represent the hours'. In reality it was far more complicated, in particular for an aperture gnomon spherical dial. He ends by indicating how the upper emplacement for the pierced bronze plaque is made but without exactly describing how its position is determined. Generally his language is descriptive, not technical. 'In effect, we mark, we place, we insert, we arrange, we lay out, we set out, we align, we lay off . . .'. There is never question of a geometrical, mathematical method, of verification, or of an astronomical analysis. Vitruvius' text, notably that concerning the analemma,[76] offers other difficulties.[77]

Unfinished dials or those with construction marks still visible are more reliable sources than the brief literary indications. However, only two unfinished dials exist. The first, conserved at Bucharest in the National Archaeological Museum,[78] was discovered at Constanta. Unfortunately, it has never been completely published and no image of it is known. That it is incomplete can be deduced from the lack of visible hour lines and that the position of the gnomon is not even marked. The second, more interesting, instrument comes from Delos.[79] It is characterized by a roughened area divided by a vertical line and bounded by a semicircle marking the area of the receiving surface. A vertical band left intact at the centre is difficult to explain as it has no technical use. Once the whole was drawn out it would be possible to hollow out the interior. Only at this moment could the hour grid be drawn and cut. This stage can be partially reconstituted thanks to construction marks surviving on some instruments. This is the case on a second dial at Delos: a conical dial with an eroded dial surface.[80] On the upper surface there are three, non-equidistant parallel lines, which seem to correspond with the internal declination lines, at least with those for the summer solstice and the equinoxes. However, the first line does not correspond with the winter solstice but rather with the position of the base of the gnomon or that of the axis for the generation of the cone.

Workshops and their personnel are just as difficult to perceive as the construction details. Nevertheless, the distribution and characteristics of archaeological finds allow two probable centres of production to be identified: Delos and Aquileia. The island of Delos contains twenty-seven dials of different types. In itself this number does not identify the island as a manufacturing centre. Pompei, for example, has furnished forty-three instruments, Rome twenty-three, and they are not considered to be centres of production. What distinguishes Delos is the presence of unfinished dials. Since it is unlikely that they would have been brought unfinished to the site, it may be supposed that a dialling workshop existed there. It is difficult to say whether this workshop contented itself with suppling the (limited) needs of the island, or whether it exported its products to Greece and Asia Minor. The case of Aquileia is different. Here no unfinished dials have been found, but a concentration of aperture gnomon spherical dials suggest that the city specialized in the making of this type of instrument. Of fourteen 'fixed' instruments coming from the city, ten are of this kind, while it is perhaps not an accident that two portable dials functioning with aperture gnomons have also been found there. Such a typological concentration has been found nowhere else in the Empire.

Generally speaking, however, apart from some specially reputed centre, there were probably not defined places of production. Many instruments would have been realized close to their future place of use, a fact confirmed by the use of local stone particularly in the western provinces of the Empire, and by the regional nature of their decoration. Thus a dial discovered at Bettwiller in Alsace was made of grey Vosges sandstone, while the supporting sculptural work comes from a local workshop. Errors in the delineation of the lines also show that the piece was not imported from a great centre of production. The craftsman had probably used existing patterns without really understanding the work of a dial maker. This is but one of many examples. Moreover the artisans employed were probably neither particularly competent, nor even trained, to produce such items. Stone-cutting centres would have responded to these slightly special orders without having specialists to complete them.

Only the designer of the object, at a superior level, had some importance. Charged with calculating and realizing the working diagram, he would need to be someone sufficiently competent to respond to the varied requests from cities and private individuals. An inscription, probably from Nicaea and dating to the first century CE, mentions one of them, a certain Aelianus Asclepiodotus:

> For good fortune, Aelianus Asclepiodotus, specialist in gnomonics, has dedicated the statue to the Goddess Nemesis.[81]

The term used, *γνωμονηκὸς*, could be a synonym for the Latin *gnomonicus*, signifying 'he who occupies himself with gnomonics', but Aelianus Asclepiodotus in this inscription certainly specifies his profession, not his hobby. The task of a professional gnomonist is, among other things, to create sundials or at least the design for these, and not to cut the stone, a task that would be consigned to others. The information summarized here is all that is available

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[76] Vitruve, *De architectura*, ix, vii. 1–7.

[77] On which see Gibbs 1976, 105–17.

[78] Gibbs 1976, 179, no 1065.

[79] Gibbs 1976,179, no 1064.

[80] Gibbs 1976, 243, no 3025.

[81] *SEG* XXXVI, 1153: αφγαθῆ/τύχ̣η/θεὰς τὰς Νεμέσεις/Αἰλιανὸς ’Ασκληπιόδοτος/γνωμονηκὸς ἀνέθηκε.

about dial makers. The case of water clock makers is even more obscure.

MEASURING TIME WITHOUT TIMEPIECES: SOME PARALLEL TECHNIQUES

For the majority of the population of the Ancient World, who were rural and more or less literate, the idea of time was fundamentally that of a measurable period. If across the centuries methods of time measurement are specific to particular societies, then Græco-Roman society had a relatively straightforward time need. Often it was no more than the simple succession of days, nights, and seasons—in all the movements of natural phenomena. What phenomena are more evident than the stars? What changes more obvious than the changes of the seasons? What proof of the movement of the Sun throughout the day is more tangible than the movement of the shadow of a man or of an instrument conceived to show it? But even before instruments were devised, other means of time recording existed that were probably known to and used by all.

Parapegmata (from the Greek verb meaning to drive in, to fix) in their simplest form are calendars showing the position of the Sun in the zodiac, stellar phases, and, sometimes, meteorological predictions. These indications were often cut in stone or drawn on walls with a series of holes around them into which a wood day-marker, or a round headed pin (*bulla* for the Romans), was pushed.[82] This pin, which had to be moved every day, is moreover close to the indicator pin used in anaphoric water clocks, as described by Vitruvius. Used at first simply as a way of following the calendar throughout the year, the *parapegmata* ended giving astronomical, astrological, and meteorological information. Those surviving do not all give the same information, nor have the same form, whence arise the difficulties in analysing them or proposing their reconstruction if they are defective.[83] Making them presupposes a certain amount of accurate astronomical and calendrical knowledge, as well as popular demand for them. To be able to predict not only the weather, but also the time of the city or the stars, without being a necessity, must have been attractive for many city dwellers. In the countryside, the natural rhythm of the seasons would have been sufficient. Popular Roman traditions transmitted by Ovid, Columella, and Pliny the Elder mark the beginnings of the seasons: for summer with the morning rise of the Pleiades; for autumn with the morning setting of Lyra; for winter with the morning setting of the Pleiades; and for spring by a meteorological, rather than an astronomical phenomenon: the first west wind, Zephyr or Favonius. This astronomical and meteorological knowledge was sufficiently widely spread that rural dwellers had no need of more sophisticated ways of for locating themselves in the year using *parapegmata* or a *menologium*. For positioning oneself in the day, it was not exactly the same, and for this, natural methods would gradually be accompanied, even supplanted, by more complex, artificial means.

The first way of dividing the day is still evident—observing the sky with the succession, free or imagined, of natural phenomena in space. The second method is less familiar—consulting a set of shadow tables to find one's position in the day—a method certainly older than that of using timepieces. The shadow table in its developed form consists of a series of columns showing the length of a shadow as a function of the time of year indicated either by a month or by the position of the Sun in the zodiac. The shadow could be given by a fixed casting element or be that cast by the observer himself. Simple, even primitive, it is known historically from Egypt whence a table has survived from the Middle Empire (2033–1786 BCE).[84] It can be found in Greece perhaps from the early fourth century BCE. Several comedies from this period mention measuring the length of one's own shadow to arrive at a dinner at the proper time. If the length of the shadow noted does not yet correspond with a particular numerical hour, the procedure is straightforward and should have sufficed to amuse the spectators of the comedies.

> *Blepyros* But who will cultivate the fields?
>
> *Praxagora* The slaves. You will have no more concern than, when the shadow is ten feet long, to go to supper fat and shiny with oil.[85]

In the play, the parasite Cherephon has already been mentioned. Now Menander, in his piece called *Kekryphales*, recalls him, and in another entitled *Anger* says:

> This man differs in nothing whatever from Cherephon. Having been invited to a supper when the shadow should be twelve feet long, he rushed in the morning to see the shadow of the Moon and arrived just as day was breaking, excusing himself for being a little late.[86]

From the Hellenistic period onwards, shadow tables were compiled as a function of the seasons, and the idea of numbered hours appeared, each shadow-length being linked to an hour of the day changing according to the season of the year. This is primordial

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[82] Petronius, *The Satyricon*, xxx, 4. 'Two tablets were fixed to the door jambs? One was inscribed, in so far as I remember, "the IIIrd of, and the day before, the Calends of January, Gaius our master will dine in town". The other showed the course of the Moon, the seven planets, the propitious and inpropitious days, marked by pins of different colours.'

[83] On *parapegmata* in general, see Pritchett 1963; Lehoux 2007.

[84] Borchardt 1920, 27.

[85] Aristophanes, *The Assembly of Women*, 651–2.

[86] Athenaeus, *The Deipnosophists*, vi, 243a.

for understanding the diffusion of timepieces, since the hour given by the shadow tables should be the same as that given by a sundial. What is more, the appearance of hours in the shadow tables seems to have coincided with the development of dials in Greek cities. These tables would be reproduced by the Romans and continue to be used into the Medieval period.[87] A 'user's manual' of one such set of tables is supplied in a Byzantine source in which an 'hour master' dedicates a shadow table to a 'King Philip'. There is no better explanation than that provided by this text:[88]

> Whatever the moment when you wish to know what time it is, I will tell you here how to proceed. At the place where you are walking you should measure your own shadow; and once you have found the shadow of your head, mark the place and walk from the place where you are, step by step. Count how many paces you take, look at the work on the wall [i.e. the shadow table] on which the months are marked. Thus you find the hour of the day for each month.

The text continues with an enumeration of the nature of each hour—fundamental evidence allowing the use of the table to be better understood.

EMBLEMATIC INSTRUMENTS: THE TOWER OF THE WINDS

Alongside the everyday instruments already presented, there also existed in Antiquity some exceptional instruments that commanded the admiration of all and have left traces in literature as well as in the urban landscape. Here we present two of the most remarkable: The Tower of the Winds in Athens and the monumental Meridian of Augustus.

The Tower of the Winds (Figure 7), built under the direction of Andronikos Cyrrestes in the second or first century BCE, is set in the centre of the city immediately beside the Roman Agora. It is a primordial building for understanding the place of time measurement in the ancient city. It is exceptional—one of the rare ancient structures to be preserved almost intact and that has been used for almost the whole of its existence.[89] However, after two and half centuries of research, many problems still surround it. Mystery surrounds the origins of its design, its function in the urbanism of the city, Andronikos' role in its conception, and the date of its construction.[90]

Nevertheless, the building is relatively well documented even from Antiquity since it is mentioned by Varro.[91] Vitruvius also mentions the Athens tower but in a wider manner:

> . . . Andronicus of Syrrhos who as proof [that there are eight winds] built the marble octagonal tower in Athens. On the several sides of the octagon he executed reliefs representing the several winds, each facing the point from which it blows; and on top of the tower he set a conical shaped piece of marble and on this a bronze Triton with a rod outstretched in its right hand. It was so contrived as to go round with the wind, always stopping to face the breeze and holding its rod as a pointer directly over the representation of the wind that was blowing.[92]

Since Vitruvius describes the building in the context of a discussion of winds, it is not surprising that he fails to mention the dials that appear on each face of the building. He would discuss dials further on in his treatise, so perhaps he had not seen the building and did not know that it carried plane vertical dials. Interestingly, it was also the winds, and not the dials, that interested M. Cetius Faventinus in the late third century CE,[93] but it is the dial that are of interest here.

They form the outstanding group of ancient planar dials.[94] Eight are engraved on the walls and a ninth on the circular annex is interpreted as the cistern of a water clock. These dials, which appear to resemble modern dials, are extremely rare in Antiquity. They are plane vertical dials calculated and engraved according to the orientation of the face on which they are placed, from direct south to direct north with other dials declining from the west to the northeast. It is a display of technical mastery showing the intellectual capacities of Andronikos, his mastery of gnomonical science, and his knowledge of astronomical phenomena.[95]

The interior of the building seems to have contained a complex water system interpreted as a water clock[96] or, more recently, as a form of planetarium.[97] Evidently nothing remains of the moving parts, but traces in the soil (of the ducts, mortises, fixing holes, etc.) together with the presence of a cistern outside the building are clear indicators of an important hydraulic system within. Above all, the building, and its collection of measuring instruments, allows us to assess the important place occupied by time

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[87] On shadow tables in general, see Neugebauer 1975, ii, 736–46; Lippincott 1999, 107 reproduces a shadow table from a manuscript of Abo of Fleury (late tenth century). For Muslim shadow tables, see King 1997, 207.

[88] *CCAG*, 7. 188.4-189-2. This explanation, although drawn from a Byzantine source, can be applied to any earlier set of tables, the underlying principles being the same.

[89] It is this that explains its excellent external state of preservation. See Webb 2017.

[90] The most recent assessments place it *c.*140 BCE. See Kienast 2014; Webb 2017.

[91] Varro, *Rural economy*, iii, 5, 17.

[92] Vitruvius I. 6. 4. Translation from Morgan 1960, 26.

[93] Cetius Faventinus II. 2.

[94] For a detailed studies of them, see Alberi 2006; Schaldach 2006.

[95] For details of Andronikos, see Bonnin 2015, 290–1.

[96] Noble and Price 1968.

[97] Kienast 2014; Webb 2017.

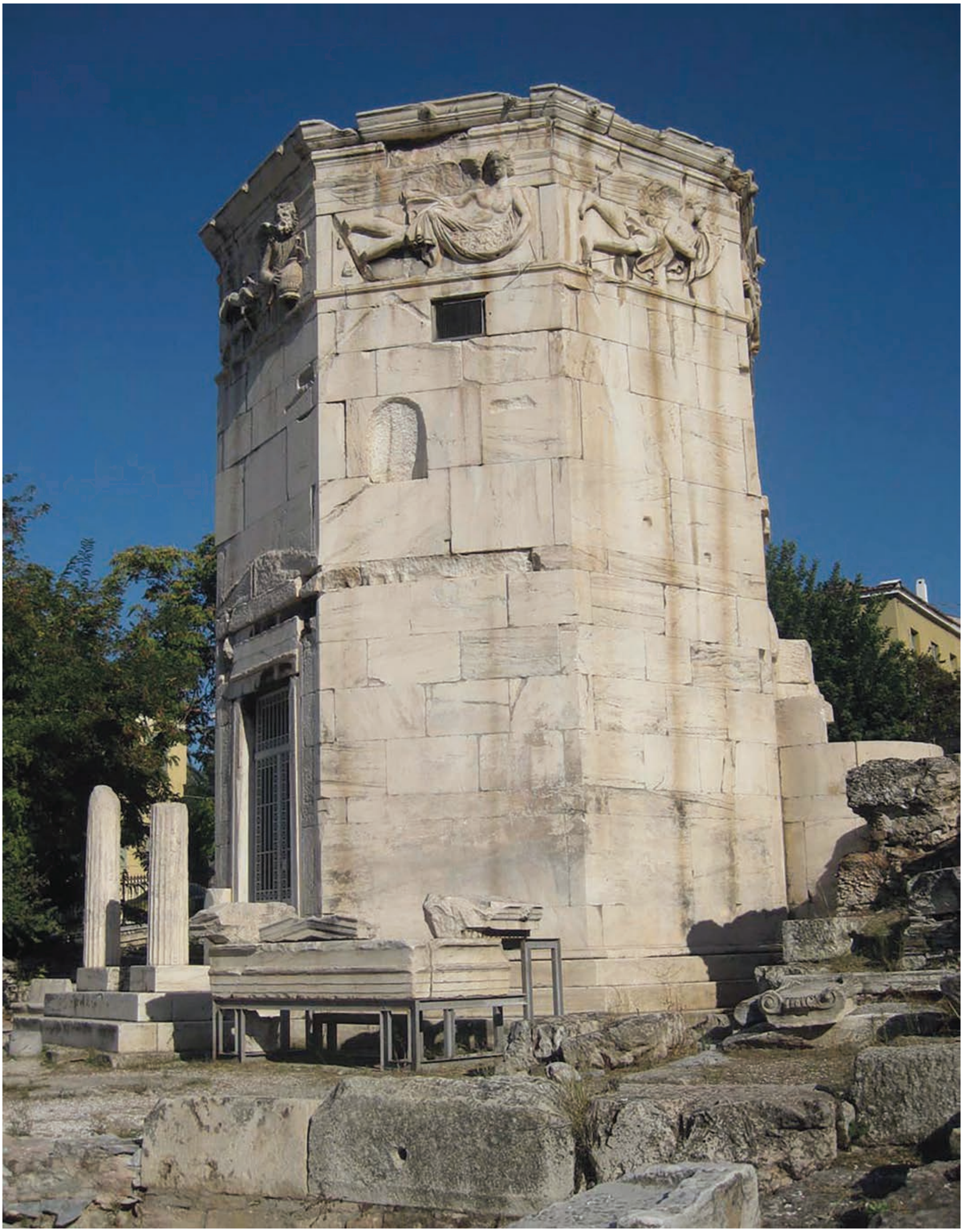

Figure 7 The Tower of the Winds, Athens, today. Photo: J. Bonnin.

measurement at the turn of the second/first century BCE. The building was ostentatious, symbolic, and uncommon in Antiquity and, as such, provoked some Latin authors to mention it. In a practical sense, it paired the natural phenomena of winds with astronomical phenomena like the sundials (and perhaps the interior hydraulic structure, which could have included an 'anaphoric' presentation). The entire assembly is a miniature cosmos: a weathervane at the summit moves as the wind changes, the shadows of the gnomons fall on the dials throughout the day, and the interior mechanism's many mobile parts (whatever they may have represented) are always in motion.

The site was chosen as a function of these imperatives: in a high place, open at the time, and close to a water source. But who had access to this structure? Was it reserved for an elite group, and regarded as a 'curiosity' to which access was strictly controlled, even closed off at certain moments? What was its purpose? Who created it? We do not know whether the commission was public or (more probably) private.

For how long did it function? From the time when the area to the west of the tower was developed, the working of the west facing and perhaps the northwest and southwest dials could have been limited, if not entirely blocked. Similarly, once the rectangular building today known as the *pseudo-agoranomion* was constructed, it certainly prevented the meridian on the circular annex from functioning. In addition, the adjacent Roman developments upset Andronikos' entire intended presentation. It was no longer possible to walk around the building to see the time on all the dials. Furthermore, the construction of the *pseudo-agoranomion* set immediately against the reservoir may have interrupted the water supply that maintained the hydraulic system. It is unlikely that the internal works still existed in the Roman period as they would have been pillaged by the troops of Sulla (138–78 BCE) after the capture and sack of Athens in 87–6 BCE. This event may explain why Varro and Vitruvius fail to describe the interior.

If the Tower of the Winds lost its scientific function quite quickly, the building nonetheless remained intact and was used for other purposes. The desire remained to provide the hour–for strictly utilitarian purposes–on the dials that were still visible. In this, we see an element constant throughout the Roman use of time measuring instruments: utility above all, with knowledge and experimentation coming second.

EMBLEMATIC INSTRUMENTS: THE MERIDIAN OF AUGUSTUS

The meridian of Augustus Caesar (63 BCE–14 CE) is one of the major monuments of Imperial Rome and of ancient gnomonics. Apart from the Tower of the Winds, no other relic of time measurement has provoked so many studies, entrenched positions, and passionate explanations. Since its rediscovery in the years 1975–1980, it has generally been referred to as the *Horologium Augusti* or the *Solarium Augusti*. More recent investigators[98] designate it the 'Meridian of Augustus', which alone is coherent with the literary and archaeological evidence.

The monument can be reconstructed thanks to Pliny the Elder who described Egyptian obelisks in Rome.[99] After surveying several, he paused over that erected in the *Campus Martius*, the first to be imported into the city, the use of which for him was particularly remarkable (*mirabilem usum*). It was not that it marked shadows and determined the length of day and night that was special, but rather that an obelisk had replaced the gnomon habitually used for this purpose, albeit on a lesser scale. Historically, pharaonic gnomons were not used for this purpose; this was the first time they were so employed. Pliny describes use of the meridian in relatively simple astronomical terms. The only novelty in what he recounts is that the progression of the shadow through the seasons is marked by bronze rules, an innovation attributed to Facundus Novius, about whom nothing else is known. Pliny's description corresponds exactly with that of a meridian.

Mostly forgotten since it fell, or was destroyed, in the eighth century, the obelisk was rediscovered at the end of the fifteenth century, and in 1748 its five broken parts were transported for re-erection in the Piazza di Monte Citorio opposite the Italian parliament. Thanks to the inscription on its base,[100] it is possible to date the original erection of the obelisk to between the months of July year 10 and June year 9 BCE. The information given there is not extensive, but the inscription mentions the Sun, Egypt, and the function of Augustus as *pontifex maximus*, three important elements concerning the meridian.

Thanks to archaeological investigations carried out between 1979 and 1981 underneath house 48 in the Campo Marzio, the meridian line mentioned by Pliny was rediscovered. The investigators uncovered a stone pavement with a band at its centre oriented exactly north–south, several inscriptions, and bronze rules.

Also found were some zodiacal signs with calendrical inscriptions. Finally, the archaeological exploration showed that during the period of Hadrian the meridian line was displaced by a reservoir and that the obelisk had also been thrust two to three metres deeper into the soil.

While currently no monument is comparable with that discovered in the Campo Marzio, nor with that described by Pliny, meridians were nonetheless familiar in Antiquity[101] and, as already noted, had a name—*heliotrope*. They were large instruments and visible from afar, as was that of Augustus. They served calendrical purposes. In Græco-Roman gnomonics, they were incorporated in many dials.

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[98] Heslin 2007 & 2011; Alberi 2011; Frischer 2017.

[99] Pliny the elder, *Natural History*, xxxvi. 2.

[100] *CIL* vi, 702.

[101] See, for example, Jones 2014, 175–88.

Today, the Meridian of Augustus is as much a monument of historiography as it is of gnomonics. No discussion of it is complete without also covering the various hypotheses about it—some proved, others not—and Buchner's is worth recounting here.

In 1976 Edmund Buchner (1923–2011) advanced a theory, based on Pliny's text and the (supposed) original height of the gnomon, to restore the form and function of the monument.[102] He supposed, in the first place, that the instrument was a gigantic sundial serving simultaneously as timepiece, calendar, and wind-rose, the obelisk itself acting as the gnomon. On the basis of the hypothetical reconstruction (made before the investigations of 1979 and 1981), he attempted to explain its purpose: the three monuments erected by Augustus on the Campo Marzio—the mausoleum, the Ara Pacis, and the *horologium*—were linked in a complex mathematical relationship. The position of the Ara Pacis, its relation to the mausoleum and the obelisk, its orientation, and its size were determined by two chief elements of the *horologium*: the equinoctial line and the circle drawn around the winter solstice. In the proposed restitution the equinoctial line is directed towards the Ara Pacis. At the Autumn equinox, which was also the birthday of Augustus, the gigantic shadow of the obelisk would indicate the Ara Pacis. At the winter solstice, the first day of Augustus' zodiacal sign, Capricorn, the circle is drawn around this point and is tangent to the south of the Ara Pacis—a link between the two monuments. The *horologium* and the Ara Pacis would thus have functioned as a birthday group, as, according to Buchner, the two monuments were consecrated in the same year, if not on the same day. The ideological implications that follow from this are obvious: the group should be understood as a public demonstration that Augustus was destined to bring back peace and assure a prestigious future to the Roman people by establishing an enduring political system.

This hypothetical reconstruction was rapidly questioned[103] because the excavations had revealed only the meridian line. The prevailing consensus today is that nothing suggests a timepiece, while everything suggests a meridian. In 45 BCE, Julius Caesar (100 BCE–44 BCE) reformed the Roman calendar so that it would correspond with the seasons. However, the following pontiffs did not understand this reform and established a leap year every three years instead of four. This meant that there was once more a lack of correspondence for thirty-six years. Then, in 9 BCE, when Augustus became *pontifex maximus* on the death of Lepidus in 13/12 BCE, he officially declared this calendar to be erroneous, re-established Caesar's work, and realigned the Roman calendar with the seasons. It was exactly at this moment that he erected the obelisk and the meridian, and his message was clear. The meridian demonstrated to everyone that it was not an ideological manipulation. At the equinoxes and the solstices the shadow touched exactly the rules representing the equinoxes and the solstices, as it did accurately for the other days of the year. The purpose of the monument was therefore calendrical and religious. Furthermore, the term *pontifex maximus* is emphasized in the inscription by not being abbreviated, which is rather rare in Latin epigraphy; this title is often abridged and is not usually deployed on a whole line.

Whatever may be its origins and its links, real or imaginary, with an ideological programme close to modern propaganda, the meridian of Augustus should be considered as an important element of the landscape of Ancient Rome. If it was not a monumental timepiece, it is nonetheless linked with time measurement—since it identifies a position in the year and shows exactly the moment of noon each day—and more importantly, carries a special, calendrical symbolism.

CONCLUSION

The trajectory of ancient timepieces is well worthy of attention. In origin the instruments were complex and prestigious. They seem to have first appeared in Asia Minor, and then in Greece well before the Romans concerned themselves with the question of time. Greek influence led to time-keeping instruments becoming a part of everyday Roman life—first in Rome itself from the third century BCE, and thereafter, following the Roman conquests, throughout the Italian peninsula. From the first century BCE there was not a city in Italy without a timepiece, and these spread to all the conquered provinces without exception. For six centuries from the second BCE to the fourth century CE timepieces would be a habitual part of 'civilized' life in both West and East. This challenges the modern presupposition that timepieces never had a great presence in Rome or much success in the Roman world. Both historical texts and archaeological remains show that it was exactly during the Roman period that time measurement became mentally embedded,[104] and that timepieces themselves became a measure of a man's civility. They were diffused throughout a vast territory and had a hitherto unknown temporal continuity. Lewis Mumford wrote that 'The clock is not just a way of following the march of the hours, it is also a means for synchronising human activity',[105] and this synchronization began in Antiquity.

The concept of a time—not uniform, but at least available everywhere for everyone—constitutes a first example of temporal control. However, one Roman characteristic should not be denied—the disappearance of all research concerning time measurement. For if the Romans inherited Greek knowledge in this matter, they also inherited the use of timepieces in daily life. The essentially scientific aspect of the first instruments in classical Greece, conserved to a lesser degree during the Hellenistic

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[102] Buchner 1976; Buchner 1982.

[103] By Heslin, 2007, 2011; Haselberger 2011; Frischer 2017.

[104] Bonnin 2013.

[105] Mumford 1934.

period, gave way to the utilitarian aspect. One went to the forum during certain hours, to the baths or the gymnasium at others. Markets opened only at specific times, as did libraries and public centres in general. Examples of the use of the hour and the timepiece are numerous. In general the common denominator of these public uses was regulation. It was obligatory to institute hours so that civic life could unfold correctly: heat the baths at the right time, avoid promiscuity, avoid overloading on the roads, summon the citizen body when needed, coordinate complex activities, or even travel with the empire in one's hand.[106]

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[106] To paraphrase the subtitle of Talbert 2017.

CHAPTER TWO

INDIA AND THE FAR EAST

SECTION ONE: HOROLOGY IN INDIA

S. R. Sarma

UNITS OF TIME MEASUREMENT

The history of horology in India has to be reconstructed from brief literary references and extant time-measuring instruments. From the earliest times, some kind of astronomical activity must have taken place for determining the seasons, the equinoxes, and the solstices for agricultural and religious purposes. The *Ṛgveda,* the earliest available text, dateable to *c.*1500–1200 BCE, contains references to seasons, to the length of the year, and so on. In an allegoric passage, it speaks of a wheel with twelve spokes that turns without stopping (alluding to the year of twelve months that repeats itself constantly) and of pairs of suns whose total number is 720 (i.e. 360 days and 360 nights).[1] The *Taittirīya-Brāhmaṇa* and the *Satapatha-Brāhmaṇa* (*c.*700–600 BCE), two later texts of the Vedic corpus, divide the civil day into 30 *muhūrtas.* The *Vedāṅga-jyotiṣa* (*c.*400 BCE), also a part of the Vedic corpus, divides the *muhūrta* into two *nāḍikās*. Accordingly, the civil day is divided into 60 equal units of *nāḍikās* (later called ***ghaṭīs***). This became the standard unit of time measurement and remained so until the end of the nineteenth century. The instruments that were used to measure this unit are the gnomon and the water clock.

GNOMON

The earliest mention of the **gnomon** occurs in the *Arthaśāstra* of Kauṭilya, which was composed and redacted between the second century BCE and the third century CE. This text lays down that the king should divide his day and the night separately into eight parts, each by means of the **water clock** (*nālikā*) or by the length of the gnomon-shadow (*chāyā-pramāṇa*), and devote each part for a specific administrative or personal task:

> He should divide the day into eight parts as also the night by means of *nālikās,* or by the measure of the shadow [of the gnomon]. [A shadow measuring] three *pauruṣas*, one *pauruṣa*, [and] four *aṅgulas* and midday when the shadow disappears are the four eighth parts of the day. By them are explained the later [four].[2]

Here Kauṭilya shows how to divide the period from sunrise to midday (n) by means of the gnomon-shadow. *Pauruṣa* (literally 'of the man') is used here in the sense of gnomon height (g). The gnomon can be of any height, but it is divided into 12 parts called *aṅgulas* ($g/12$). At sunrise, the shadow length is three times a man's height (*pauruṣa*), which actually means thrice the gnomon's height ($3g$). When the shadow length is $1g$, it is ¼ n from sunrise; when it is four *aṅgulas* ($4/12 = 1/3g$), it is ¾n from the sunrise. When there is no shadow it is midday. The same shadow lengths in the reverse order indicate the four parts of the time between midday and sunset. But these shadow lengths are correct only on equinoctial days. For other times, an increase of two *aṅgulas* per month in shadow lengths is prescribed.[3]

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[1] Griffith 1889, 1.164.11.

[2] Kauṭilya 2010, 46

[3] Jacobi 1920, 253–4.

S. R. Sarma, *India and the Far East.* In: *A General History of Horology.* Edited by Anthony Turner, Jonathan Betts, and James Nye, Oxford University Press.
DOI: 10.1093/oso/9780198863915.003.0002

Thereafter, no information is available until Brahmagupta composed the *Brāhma-sphuṭa-siddhānta* in CE 628. The third chapter of this text is designated 'the chapter on three questions or topics' and discusses the determination of the cardinal direction (*diś*), terrestrial latitude (*deśa*), and time (*kāla*) by means of the gnomon (*śaṅku*). As in the *Arthaśāstra*, a straight staff is set up temporarily on a level ground on which lines are drawn for the determination of these three parameters and others, such as the times of sunrise and sunset, rising of the zodiac signs, the ascendant, and so on. This practice of devoting the third chapter to gnomonics is emulated by nearly all the Sanskrit texts of the genre *Siddhānta*.

The *Brāhma-sphuṭa-siddhānta* describes some other instruments of permanent nature and so do several subsequent texts.[4] Although many types of instruments are described in these texts for measuring time by the sunlight, those that are represented by extant examples are just three: the ring dial (*Cūḍā-yantra*), the column dial (*Kaśā-yantra*), and the horizontal dial with a triangular gnomon (*Palabhā-yantra*).

Ring dial (*Cūḍā*-yantra)

The earliest of these is the ring dial.[5] Here, a small hole in the breadth of the ring allows sunlight to fall upon the inner concave surface of the opposite side, which is graduated in degrees to measure the solar altitude. Local time can also be measured directly if the inner surface is provided with separate scales for each solar month.

The ring dial was first described by Āryabhaṭa about the beginning of the sixth century CE in his *Āryabhaṭa-siddhānta*[6] and by Varāhamihira in his *Pañcasiddhāntikā* in the middle of the sixth century CE.[7] In his *Yantraprakāśa* (1427), Rāmacandra Vājapeyin describes three varieties that work on the same principle but differ in size. The *Valaya-yantra* measures a **cubit** in diameter, the *Cūḍā-yantra* a **span** or less, and the *Mudrikā-yantra* is much smaller. The inner concave surface is graduated in *ghaṭīs* for measuring time and the rim in 360 degrees for measuring the solar altitude.[8]

Of these, the *Cūḍā-yantra* appears to have been more popular; it is represented in several Mughal miniatures, where astronomers are depicted holding a small ring dial to measure the solar altitude, and not the astrolabe as might be expected.[9] Because of its frequent occurrence in paintings depicting the Mughal court, one is apt to think that it may have been of Islamic origin. But the ring dial was not known to the Islamic world and must have been developed in India itself.

Sawai Jai Singh of Jaipur (1688–1743), before he designed the huge masonry instruments for his observatories at Delhi, Jaipur, and three other places, caused the compilation of the *Yantraprakāra* between *c.*1716 and 1724, which deals with the construction and use of several portable instruments, culled from diverse sources. This text contains a detailed description of the *Cūḍā-yantra*, together with an elaborate set of tables to be used in conjunction with it. There are nineteen separate tables, all for the latitude of Delhi (28°39′). The first and last of these tables are prepared for the first **decans** of Capricorn and Cancer respectively; of the remaining seventeen tables, each one is meant for a pair of opposite decans.[10]

Compared with horizontal and vertical sundials, the ring dial is more difficult to construct and also more difficult to use. It is probably for this reason that only three examples are extant. Two well-crafted specimens are preserved in Jai Singh's Observatory at Jaipur (Figure 8). These must have been made for Jai Singh himself in the first quarter of the eighteenth century at Jaipur. The third, of an inferior make, is in the Museum of Indology at Jaipur.

Column dial (*Kaśā-yantra*)

The column dial, also known as cylinder dial, consists of a straight wooden staff, with a circular or prismatic cross-section, divided lengthwise into several columns, each carrying a separate scale of *ghaṭīs* for measuring time in a particular solar month.[11] The *ghaṭīs* are numbered serially from the top to the bottom according to the length of the half-day from sunrise to midday in that particular season. In the upper part, just above the scale, is a hole in each column to receive the horizontal gnomon.

For measuring time, the horizontal gnomon is inserted into the hole above the scale meant for the current solar month and the staff turned slowly towards the Sun so that the gnomon throws its shadow exactly on the scale below. Where the end of the shadow touches the numbered scale, the number indicates in the forenoon the *ghaṭīs* that have elapsed since the sunrise, and in the afternoon, the number of *ghaṭīs* that are to elapse up to sunset.

The column dial is described in four Sanskrit texts that were composed between 1428 and 1439.[12] In these texts, the column dial is called *Cābuka-yantra*, *Kaśā-yantra*, or *Pratoda-yantra*. *Cābuka* is a loan word from the Persian and denotes a horsewhip; *Kaśā* and *Pratoda* are Sanskrit renderings of the Persian term. This suggests that the instrument was borrowed from the Islamic world.

The earliest column dial surviving from the Islamic world was made by Abî al Farāj ʿĪsā in AH 559 (1163/64 CE). It has twelve columns and the hours on these are divided by continuous curves.[13] In the thirteenth century, al-Marrākushī also describes

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[4] Cf. Sarma 1986–1987a.

[5] Sarma 2019a, Section O.

[6] Shukla 1967, 93, 98; Ôhashi 1994, 236–8.

[7] Varāhamihira 1968, 80; Ôhashi 1994, 238–9.

[8] Rāmacandra, 1886–92, 61–2.

[9] Sarma 1992, 249–52.

[10] Sarma 1986–1987b, 27–8, 79–82, 105–14.

[11] Sarma 2019a, Section P.

[12] Ôhashi 1998.

[13] Casanova 1923; Turner 2018, 187–9.

Figure 8 Ring dial from the Jai Singh Observatory, Jaipur. Photo: S. R. Sarma.Column Dial (*Kaśā-yantra*).

the column dial in the same manner.[14] But neither source contains any reference to a horsewhip.

The column dial has a continuous history in Europe since Late Antiquity.[15] In Europe there exist in museums several Renaissance and later specimens, but only a few Islamic examples have survived.[16] Both the Islamic and the European specimens differ in construction from the extant Indian examples. They are much smaller, with lengths of about 200mm. The twelve scales on their columns are divided by continuous curves that flow from one to another. The top with the gnomon can be rotated so that the gnomon rests on the desired month.

Compared with these, the Indian versions are much longer, ranging between 1100mm to 1550mm. Instead of twelve separate scales for the twelve solar months, they usually have eight scales, employing one common scale for two solar months that are at equal distance from the equinoxes. The scales are not divided by continuous curves, but by straight lines unconnected with those on the adjacent column. In other words, these are cruder imitations of those produced in the Islamic world and in Europe. It is clear that the idea of the column dial came from the Islamic world—we cannot identify the exact process of transmission—but the Sanskrit authors merely borrowed the name, not the principal feature, namely, marking the hours on the different scales by continuous curves.

The extant specimens of Indian column dials are of three types: those made of metal or ivory, those made of wood on which scales are painted, and those made of timber on which the scales are carved. There exist just two specimens of the first group. The first is an exquisitely crafted steel column dial in the museum of the History of Science, Oxford, 95.6cm, with all the scale lines, numbers and decorative patterns inlaid in gold (Figure 9). It is topped with an ornate finial and the other end terminates in a sharply polished blade. It must have been created for some prince in Rajasthan. The other, made of ivory, is also of excellent workmanship, with a beautifully carved finial at the top and an ornate end at the bottom; it was in the now-defunct Time Museum, Rockford, Illinois, USA.[17]

In the second category are wooden column dials on which the scales and numbers are painted. There exist three specimens of no great merit.[18]

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[14] Ōhashi 1998, 195–196.

[15] This volume Chapter 3. ii; Zinner 1979, 50–1.

[16] See Chapter 3, Part One and Part Two. Ottoman pillar dials are held in the Institut du Monde Arabe, Paris (Naffah 1989), the Adler Planetarium, Chicago (Pingree 2009, 222), and two in the Kandili Observatory, Istanbul (Danisan 2020).

[17] Published in Sotheby's 2004, 194, no. 717.

[18] One of these is in Jai Singh's Observatory, Jaipur, the others in the Shri Sanjay Sharma Museum & Research Institute, Jaipur.

Figure 9 Column dial of damascened steel, Museum of the History of Science, Oxford, Inv. no. 50,041. Photo: S. R. Sarma.

The third group is the largest with some eighteen specimens, their lengths varying from 1034mm to 1541mm.[19] On these the numbers and letters are carved in relief. Designed for a latitude of about 27°, they were produced in the Himalayan foothills in the region of Darjeeling (27° 3′ N, 88° 16′ E) and Kalimpong (27° 3′ 36″ N, 88° 28′ 12″ E). Nearly all these column dials are equipped with an iron spike at the bottom, which has to be set in the ground so that the column stands upright and the scale for the current month faces the Sun. Two of them carry dates that correspond with 1869 and 1884 CE; the others must have also been made about the same time in the later nineteenth century. All the extant specimens are in museums and private collections outside India.

Horizontal dial (*Palabhā-yantra*)

In the *Palabhā-yantra,* the horizontal sundial is equipped with a triangular gnomon, the hypotenuse of which points to the north celestial pole.[20] Like the column dial, this one is also borrowed from the Islamic world. The earliest known specimen was made by Ibn al-Shāṭir in the second half of the fourteenth century for the Umayyad Mosque, Damascus.[21] From the Islamic world, it was transmitted westwards to Europe and eastwards to India. Because of the simplicity of its construction, it was frequently produced in Europe and North America.

In India it was absorbed into the Sanskrit repertoire of instruments under the title of *Palabhā-yantra*. *Palabhā* denotes the noon equinoctial shadow, i.e. the length of the shadow thrown by a gnomon at midday on the days of the equinox. A *palabhā-kṣetra* then is a right-angle triangle where the length of the shadow forms the base and the height of the gnomon the vertical. The hypotenuse of this triangle subtends an angle that is equal to the terrestrial latitude of the place. For measuring time, the instrument is so set up that the gnomon rests on the north–south line upon a horizontal dial that is divided into *ghaṭīs*. The angles separating the *ghaṭī* lines will be unequal. Since the gnomon is fashioned according to the terrestrial latitude of a specific locality, it can be used only at that latitude.

The *Palabhā-yantra* is described for the first time in the *Yantraprakāra* in the early eighteenth century.[22] This text teaches how to calculate the angles between the hour lines on a horizontal dial for the latitude of Delhi at 28° 39′ and for that of Amber at 27°. Thereafter, the *Yantraprakāra* provides a table showing the angular distances between the lines indicating one *ghaṭī* up to fifteen *ghaṭīs* for the latitudes of Delhi and Amber. There are several other eighteenth-century texts that describe it.

The instrument appears to have been popular in Rajasthan. In Sawai Jai Singh's Observatory at Jaipur, a *Palabhā-yantra* is incorporated at the top of the *Nāḍīvalaya-yantra*. The Observatory also owns a *Palabhā-yantra* made by Gokula Nātha Sarmā in 1882 (Figure 10). There must have been several others erected in public places. Some have been removed and preserved in museums, many are lost.

WATER CLOCKS

An obvious disadvantage with sundials is that they can be used only in daytime and only at the latitude for which they were designed. In contrast, **water clocks** can be used both in the day as well as in the night, and at all latitudes. In India **outflow water clocks** and **sinking bowl clocks** were used, not simultaneously but one after the other. Both types were designed to measure the same unit of time, namely, one-sixtieth part of the nychthemeron. In the texts where the outflow water clock is mentioned, this time unit is mentioned variously as *nālikā*, *nālī*, *nāḍikā*, or *nāḍī*. For convenience, we shall use the form *nāḍikā*. But the instrument itself is not mentioned by any name; it will be called *Nāḍikā-yantra*. The sinking bowl type of water clock is mentioned as *ghaṭikā-yantra*, *ghaṭī-yantra*, or *jalaghaṭī-yantra*, and the unit of time measured by it as *ghaṭikā* or *ghaṭī*. Here also, for the sake of consistency, the instrument will be referred to as *ghaṭikā-yantra* and the time unit as *ghaṭī*.

Outflow water clock

The outflow water clock (Figure 11) is described in four texts: the *Vedāṅga-jyotiṣa*, *Arthaśāstra*, *Śārdūlakarṇāvadāna*, and *Jyotiṣkaraṇḍaka*.[23] The dates of the first two texts are given above;

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[19] Winter 1964 describes an undated specimen at the John Gershom Parkington Memorial Collection, Bury St Edmunds, Suffolk, UK.

[20] Sarma 2019a, Section N.

[21] Berggren 2001, 12.

[22] Sarma 1986–1987b, 26, 76–7.

[23] The first three sources are discussed in Fleet 1915.

Figure 10 *Palabhā-yantra* made by Gokula Nātha Śarmā in 1882, Jai Singh Observatory, Jaipur. Photo: S. R. Sarma.

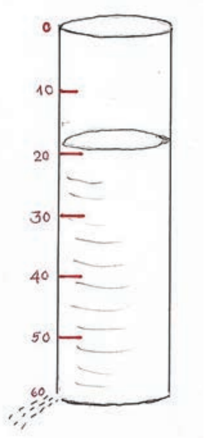

Figure 11 Outflow water clock (*Nāḍikā-yantra*).

the last two texts belong roughly to the early centuries of the Christian era. The descriptions they give are extremely brief and not very coherent. In the absence of actual specimens, it is difficult to interpret these sources properly.

The outflow water clock there described consists of a vessel with a very small hole at the bottom through which the water in the vessel flows out and indicates time. The shape and size of the vessel are not mentioned. The names of the time unit *nālikā* or *nālī* are diminutive forms of *nala*, which denotes, among other things, a reed or a tube, or a hollow cylinder. Accordingly, the vessel must have been of cylindrical shape. A cylindrical vessel has the advantage that its height can easily be divided to show the water level at various subdivisions of a *nāḍikā*.[24]

On the amount of water with which the vessel was to be filled, the texts make contradictory statements. However, since the length of the day varies according to seasons, the *Vedāṅga-jyotiṣa* prescribes that a *prastha* of water should be added every day when the length of the daylight or of the night increases and the same amount of water is removed when the length decreases.[25]

The most remarkable feature is the prescription regarding the size of the hole at the bottom of the vessel. The *Arthaśāstra* and the *Jyotiṣkaraṇḍaka* prescribe that the hole should be so large that a gold wire, four *māṣas* in weight and four *aṅgulas* long, should just fit into it. The *Śārdūla-karṇāvadāna* retains the length of four *aṅgulas*, but prescribes one *suvarṇa* weight. As pure gold is malleable, a gold wire of a uniform diameter can be drawn with a given weight of gold. The hole being a minute one, there is no better way of defining it. The Babylonian and Chinese records on outflow water

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[24] The cylindrical shape is confirmed by Bīrūnī, 1910, i, 334, who visited India in the first quarter of the eleventh century.

[25] Lagadha 1985, 44.

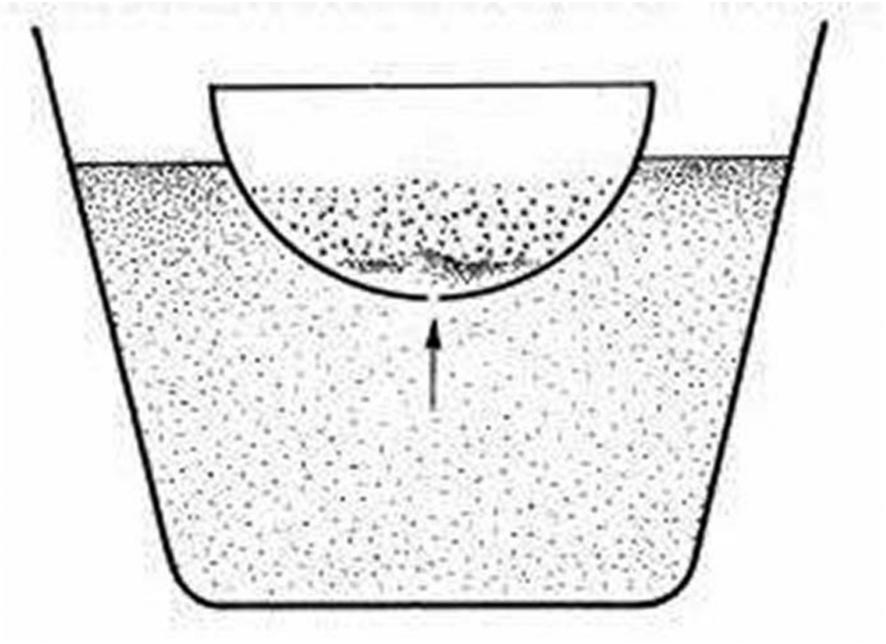

Figure 12 Sinking bowl water-clock (*Ghaṭikā-yantra*).

clocks do not appear to be familiar with this method. Therefore, this method of micro-measurement may have developed in India. Even when the outflow water clock was replaced by the sinking bowl type, the dimension of the hole in the bowl was defined in a similar manner, as will be shown later.

Jacobi argues that, in a cylindrical vessel, as the water level goes down the pressure decreases, and so does the speed of discharge through the hole at the bottom. Consequently, the time units indicated by this device will not be of a uniform duration; they will be shorter at first and then become longer and longer. Therefore, the outflow water clock was gradually replaced by the sinking bowl type of water clock.[26]

Sinking bowl water clock

The sinking bowl water clock (Figure 12) consists of a hemispherical bowl made of a thin sheet of copper with a fine hole at the centre of the bottom. When this bowl is floated on water in a larger basin, water percolates into the bowl through the hole and fills it, and the bowl sinks. The bowl is then lifted up, emptied, and set up once again on the surface of the water. The hole is so made that the bowl sinks sixty times across a day and a night, i.e. the bowl takes 24 minutes to fill and sink. Since the bowl is called *ghaṭikā* or *ghaṭī* (diminutive form of *ghaṭa*, 'pot'), the time unit measured by this instrument also came to be called *ghaṭikā* or *ghaṭī*.

Āryabhaṭa is the first author to describe the *Ghaṭikā-yantra* in his *Āryabhaṭasiddhānta*:[27]

> Get a round (i.e. hemispherical) bowl made with ten *palas* of copper. Let its height be six *aṅgulas* and the diameter at the mouth twelve *aṅgulas.* Get a hole bored at its bottom [so that a gold wire] one *pala* [in weight] and eight *aṅgulas* [in length can pass through it].

After Āryabhaṭa, this instrument is described in several astronomical texts.[28] Lalla (eighth or ninth century), in his *Śiṣyadhīvṛddhidatantra*, while retaining the dimensions of the bowl, changed the size of the perforation—from the gold needle of one *pala* weight and eight *angulas*' length to a gold needle three and one-third *māṣas* in weight and four *aṇgulas* in length.[29] Since sixty-four *māṣas* make one *pala*,[30] the perforation prescribed by Lalla would be 5/48th of that prescribed by Āryabhaṭa. While the size and weight of the bowl remain the same, such stark reduction in the size of the perforation will greatly increase the duration of the time needed for the bowl to fill and sink, and consequently the duration of the *ghaṭī* as well. One is therefore led to suspect that these specifications are fictitious and have no connection with actual practice. Therefore, Bhāskarācārya in his *Siddhāntaśiromaṇi* (1150) dismisses these prescriptions as illogical and difficult to implement.[31]

In spite of this confusion in the textual prescriptions, countless specimens must have been made throughout the centuries and these must have kept reasonably correct time of one *ghaṭī* of twenty-four minutes. But it is doubtful whether any artisan has ever produced a bowl precisely according to the textual prescriptions. In the few specimens that survive in modern collections, the bowls rarely have the exact shape of a hemisphere (Figure 13). The sizes and weights also vary considerably. The holes were obviously

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[26] Jacobi 1920, 251.

[27] Shukla 1967.

[28] Some of these descriptions are translated and discussed in Sarma 2004, 303–10.

[29] Lalla 1981, part i, 246.

[30] Śrīdhara, text, 5; translation, 3.

[31] Sarma 2019b, 332.

Figure 13 Water clocks in the Pitt Rivers Museum of Ethnology, Oxford. Upper row, left to right: from Mirzapur, Myanmar, unknown source; Second row: from Rampet, unknown source, Sri Lanka; Bottom row: made of coconut shell from Malabar. Photo: S. R. Sarma.

made by trial and error, comparing the new bowl with one that showed the correct time.

HOROLOGICAL VOCABULARY

Even after the *Nāḍikā-yantra* was completely replaced by the *Ghaṭikā-yantra*, the terms related to the older device—*nālikā*, *nāḍikā*, *nāḍī*—continued to be used along with the new terms *ghaṭikā* and *ghaṭī* to denote the basic unit of time of twenty-four minutes. From these two sets of terms, two other sets of names are derived to designate the sixtieth part of a *ghaṭī* (i.e. twenty-four seconds), for example, *vināḍikā*, *vināḍī*, and *vighaṭikā*, *vighaṭī*. But this unit is more frequently called *pala* in northern India.

The influence of the *Ghaṭikā-yantra* on the horological vocabulary is all-pervasive in India. In many modern Indian languages, timekeeping devices, however sophisticated they may be, are still called *ghaḍī* (from Sanskrit *ghaṭī*). The term *ghaṭikālaya*, originally the designation of the timekeeping establishment, engendered the names of the timekeeping devices in Telugu (*ghaḍiyāramu*, *gaḍiyāramu*) and Malayalam (*gaḍigāram*); it also gave rise to the term *ghaḍiyāl*, which denoted the 'gong' in North India and clock in Gujarati. Finally, in many Indian languages, when it is, for example, four o'clock, one says 'it is striking four' or something similar; such an expression is not derived from the chimes of the European clocks but from the old practice of striking the *ghaṭīs* on a gong.

Measuring the fractions of a *ghaṭī*

Sanskrit sources suggest an ingenious method for measuring the fractions of a *ghaṭī*. It was mentioned above that Āryabhaṭa divides the *nāḍikā* into sixty *vināḍikās* and each *vināḍikā* into sixty long syllables; that is to say, a *vināḍikā* is the time taken to utter sixty long syllables. Therefore, concludes Varāhamihira, a *nāḍikā* or *ghaṭī* is the time taken to recite sixty times a verse made up of sixty long syllables.[32] Hence, if one wishes to measure four *ghaṭīs* and twenty-one *palas* since sunrise, one sets the perforated bowl upon the water when half the solar orb rises above the horizon. After four immersions of the bowl, one recites twenty-one times a verse consisting of sixty long syllables.

Another possibility is to mark the divisions of the *ghaṭī* on the inner side of the vessel, but it is very difficult to graduate geometrically the inner wall of the small bowl into sixty

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[32] Varāhamihira, 14.32; interestingly, this verse itself is made up of sixty long syllables! For three other verses of this nature, see Sarma 2004, 320–2.

vighaṭīs. But it should be possible to empirically divide the bowl, if not into sixty parts, at least into ten parts (= 2 min 24 sec) each. Gilchrist reports in 1795 that in some specimens he saw in Bengal, the bowl was marked with divisions.[33] Mrs Meer Hasan Ali[34] and Thurston[35] also speak of the marks made on the bowl to indicate the subdivisions. However, during my survey I did not come across a single specimen with such marks of graduation.

Prahara and yāma

While time was measured in equal *ghaṭīs* for astronomical and astrological purposes, for common people broader segments were sufficient, such as the fourth part of the day and of the night. The fourth part of the day is called *prahara* and that of the night *yāma*, although *prahara* is frequently used for both day and night. These time units were announced by strokes on a drum at a central place and hence were called *prahara* (literally 'stroke'). The duration of this *prahara/yāma* is variable according to the geographical latitude and the season. Astronomical texts hardly mention *prahara* or *yāma*, but they occur in other texts.

This raises the question how the variable *prahara* was measured with water clocks, which measured only the fixed unit of one *ghaṭī*? In other words, how were the variable units of *prahara* reconciled with the fixed units of *ghaṭīs*? On this, there is no evidence before the mid-sixteenth century, but then it appears that, although the *prahara* is one-fourth of the daylight, in practice, however, the *praharas* are so arranged that they always consist of an integral number of *ghaṭīs*.

John Gilchrist explains how this was done with the help of an elaborate 'Hindoostanee Horal Diagram.' According to him, in a day all the *praharas* were not of equal length but each *prahara* consisted of an integral number of *ghaṭīs*. Thus, on equinoctial days, the first and fourth *prahara* of the day consisted of eight *ghaṭīs* each, whereas the second and third contained seven each, making a total of thirty *ghaṭīs*. This would mean that the second *prahara* ends at noon, thus dividing the day into two equal parts. Secondly, the length of the *prahara* is not adjusted every day, but only when the day or the night becomes longer or shorter by two *ghaṭīs* (forty-eight minutes).[36]

Ghaṭikā-yantra in inscriptions and literary texts

Institutions for timekeeping are attested, from the seventh century onwards, at Buddhist monasteries, royal palaces, town squares, and the like, where time was measured constantly with the water clock and the passage of each *ghaṭī* and completion of each quarter of the day (*prahara*) or of the night (*yāma*) was broadcast. There are references to endowments made for the maintenance of the attendants. Ideally, there should always be two attendants, one to lift the bowl and empty it when it has sunk, the other to announce the completion of the *ghaṭī*. There should be at least four such pairs who take turns: two in the day and two at night. Of course, to lift the bowl, empty it and replace it carefully on the water surface takes time; at a minimum of fifteen seconds for the process, it will make a difference of fifteen minutes, when this is done sixty times in a day and night.

The Chinese traveller I-Tsing (modern spelling Yi Jing), who spent some ten years (*c.*675–85) at the Buddhist monastery of Nālanda, gave a detailed account of the timekeeping establishment there; time was measured by means of sinking bowl water clocks and announced by means of drums and conch shells.[37] He adds that these water clocks, 'together with some boys are the gifts from kings of many generations, for the purpose of announcing hours to monks.' At the beginning of the eleventh century, Al-Bīrūnī reports about a timekeeping establishment in Peshawar:

> The Hindus have a popular kind of division of the nychthemeron into eight *prahara*, i.e. changes of the watch, and in some parts of their country they have clepsydrae regulated according to the *ghaṭī*, by which the times of the eight watches are determined. After a watch which lasts seven and half *ghaṭī* has elapsed, they beat the drum and blow a winding shell called *śaṅkha*, in Persian *sped-muhra*. I have seen this in the town *Purshūr* [Peshawar]. Pious people have bequeathed for these clepsydrae, and for their administration, legacies and fixed incomes.[38]

The buildings which house the water clocks are called *ghaṭikālaya*, *ghaṭikāgṛha*, or *ghaṭīgṛha* in inscriptions and other documents from Gujarat belonging to the thirteenth and fourteenth centuries. For example, the *Lekha-paddhati*, a collection of model drafts for official and private documents, compiled in the thirteenth century, lists *Ghaṭikāgṛha-karaṇa* among thirty-two administrative departments (*karaṇa*); this would then be the department which maintains and supervises timekeeping establishments in different cities in the kingdom.[39]

The water clock house is pictorially depicted on the wooden cover of a palm-leaf manuscript (*c.* thirteenth century).[40] Both the sides of this cover are painted with events related to the historic debate between Vādi Devasūri of the Śvetāmbara Jain sect and the monk Kumuda Candra of the Digambara Jain sect, which took place at the court of Siddharāja Jayasiṃha at Patan in 1124 and in which Devasūri emerged victorious.

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[33] Gilchrist 1795, 87.

[34] Ali 1974, 55–6.

[35] Thurston 1907, 565–6.

[36] Gilchrist 1795, 83.

[37] I-Tsing 1896/1966, 144–6. For a critique of his account, see Sarma 2019a, 3779–83.

[38] Bīrūnī 1910, i, 337–8.

[39] Strauch 2002, 240–1. For other sources, see Sarma 2019a, 3784.

[40] Chandra 1949, 59–62, Figures 193–8; Sarma 2019a, 3785–7.

The front side of the cover is devoted to scenes at Āśāpalli (modern Ahmedabad) where Devasūri was challenged for a debate by Kumuda Candra. Here, next to the shrine of Neminātha, is a structure identified by the label above as the *ghaṭikāgṛha*. No details of the water clock or of the attendants are shown, except the half-open door between two pillars. Above the pillars is the roof with a parapet consisting of a series of roundish battlements.

The reverse side contains scenes from the city of Pāṭan where the debate was to be held at the court of King Jayasiṃha. Here, the *ghaṭikāgṛha* is depicted next to the royal harem. One sees just the back of the house. It is, however, noteworthy that in both cities the *ghaṭikā-gṛhas* are located at central places; at Āśāpallī next to the shrine of Neminātha and at Pāṭan next to the royal harem. This would suggest that the *ghaṭikā-gṛha* was an important feature in the urban landscape of twelfth-century Gujarat.

Three inscriptions (dated respectively 1228, 1403, and 1404) from the Telugu-speaking region on the east coast refer to the endowments made for timekeeping with water clocks (*ghaḍiyāramu*) at Hindu temples.[41] Besides these inscriptions, several Telugu literary works also contain references to water clocks.[42]

WATER CLOCKS AT THE COURTS OF THE TUGHLUQS AND MUGHALS

In the first half of the eleventh century, al-Bīrūnī described the announcement of time by drum and conch shell. During the next centuries, these sound-producing instruments appear to have been replaced by the brass or bronze gong (*ghaḍiyāl*) on which a series of rapid blows separated the strokes for the *ghaṭīs* and those for the *praharas*. The Muslim rulers of Delhi adopted the water clock and the gong.

Shams-i Sirāz ʻAfīf, a contemporary and chronicler of Fīrūz Shāh Tughluq, the Sultan of Delhi (1351–88), narrates that the Sultan installed the *ṭās-i ghadiyāl* at his palace.[43] Afīf does not provide any description of the device. But the Persian word *ṭās* means ʻcup' or ʻbowl' and therefore the expression *ṭās-i ghadiyāl* stands for the ensemble of the sinking bowl and the gong.

Bābur (r. 1526–30), the first Mughal emperor, was so impressed by this system of timekeeping that he adopted it and introduced improvements in the mode of announcement.[44] The same system continued in Akbar's reign (1556–1605) as reported by his chief chronicler Abū al-Faḍl.[45] More importantly, the water clock is depicted very accurately in two miniature paintings executed in Akbar's atelier.[46] Indeed, these are the only pictorial depictions of the device. The first painting relates to the birth of Akbar.[47] It shows Akbar's father Humāyūn seated on a throne, with astronomers in attendance. They have measured the time of birth by means of a water clock and a ring dial and drawn up the horoscope. The water clock, with the bowl floating in a large basin, is drawn very clearly. The second miniature is related to the birth of Akbar's son Jahāngīr. It depicts the Hindu and Muslim astronomers seated together, measuring the time of birth with a water clock, the Sun's altitude with a ring dial, and drawing up the horoscope.[48]

The sinking bowl type of water clock was in use throughout India until the end of the nineteenth century. Powell reports in 1872 that ʻ[t]his article is in common use, and by it all police guards, &c, keep the time, striking their gong as each hour comes round.'[49] One would therefore expect scores of water clocks to be surviving in every part of India. But in India unused copper or brass vessels are generally recycled and therefore there are few specimens extant. Of late, some former Maharajas have established museums inside their palaces and display artefacts of historical interest. Thus, in the palace museums at Bharatpur, Bundi, Kota, Udaipur (all in Rajasthan), and Ramnagar (in Uttar Pradesh), the time apparatus of perforated bowl, water basin, and gong is displayed.

The largest collection of water clocks—of different shapes, sizes, and materials—is preserved in the Pitt Rivers Museum of Ethnology, Oxford (Figure 13). While some of these were made to measure the traditional Indian unit of *ghaṭī* or its fractions, others were made to measure the hour of sixty minutes, introduced by the British colonial administration, or its fractions. Yet there is one more specimen which was not intended to measure time as such, but to measure the duration of irrigation water supply into different fields.

ORIGIN AND DIFFUSION OF THE SINKING BOWL WATER CLOCK

The sinking bowl type of water clock was not confined to India, but rather was used in many countries from Iran to Spain in the west and from Myanmar to Indonesia in the east. It was used not only for regular timekeeping, but also to measure segments of time for the distribution of irrigation water in the west and to measure segments of time in cock fights in Southeast Asia. But where did it originate?

The earliest mention of the sinking bowl occurs in the Pali commentary of the *Majjhimanikāya*, written by Buddhaghoṣa in

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[41] Sarma 2019a, 3788–92.

[42] Sarma 1948, 324–7.

[43] Elliot & Dowson 1871, III, 338.

[44] Bābur 2006, 516–17.

[45] Abū al-Faḍl, 17–18.

[46] Sarma 1992, 241–3.

[47] British Library, Ms Or. 12,988, f. 20b. Sen 1984, 130–1, Pl. 57.

[48] Museum of Fine Arts, Boston, 17.3112. Welch 1978, 70–1, Pl. 16.

[49] Powell 1872, 200.

the first half of the fifth century CE in Sri Lanka.[50] This commentary narrates the use of a sinking bowl that measured one *yāma*. at a Buddhist monastery. At the low geographical latitude of Sri Lanka, *yāma* may have been treated as equal to the constant value of 3¾ *ghaṭīs*. Bowls that measured one *ghaṭī* must be still older. It is therefore reasonable to suppose that the sinking bowl type of water clock was developed some time in the fourth century in the Indian Ocean region, either in Sri Lanka, or on the southern coast of India. It is also likely that the original inspiration for the sinking bowl came from the coconut shell, which is naturally endowed with a hole; water clocks made of well-scrubbed halves of the coconut shell survive in museums.

There is, however, one problem with this scenario. The use of the sinking bowl in Iran was mainly associated with the distribution of irrigation water from the underground water channels called *qanāt*. While this *qanāt* system is said to be very ancient,[51] it is not known when the distribution of irrigation water to individual farmers began to be regulated by means of the sinking bowl. Therefore, it is difficult to say whether the sinking bowl used with the *qanats* reached India and from there spread to Southeast Asia, or whether it originated either in Sri Lanka or India, and thence spread westwards and eastwards.

The sinking bowl as an irrigation clock

The *qanāt* system spread from Iran to other areas in the Middle East and then to North Africa and Spain. In some of these places, distribution of water to individual cultivators was regulated by sinking bowls. For their use in Iran, Wulff offers a very detailed account,[52] as does Glick for North Africa and Spain.[53]

The sinking bowl may have been used as an irrigation clock in India also, but there do not seem to be any published records of this. The only tangible evidence is a copper bowl from Rampet, Pallar Valley, in Tamilnadu, in the Pitt Rivers Museum, Oxford (Figure 13).

Nepal For Nepal, Thurston reports as follows:[54]

> In Nepāl the measurement of time is regulated in the same manner [as in India]. Each time the vessel sinks, a gong is struck, in progressive numbers from dawn to noon. After noon, the first ghari struck indicates the number of gharis which remain of the day till sunset. Day is considered to begin when the tiles on a house can be counted, or when the hairs on the back of a man's hand can be discerned against the sky.

In Kathmandu, at Hanumandhoka Palace, and also at Gorkha Palace, it is said that time was measured with a water clock and announced regularly up to the beginning of the twentieth century. Recently, Olivia Aubriot studied the irrigation system in a village in central Nepal and reported that the sinking bowl was used there as the irrigation clock.[55]

Sri Lanka The large sinking bowl that measured one *yāma* in the fifth century CE at a Buddhist monastery in Sri Lanka has already been mentioned. It is not known how time was measured in subsequent centuries in Buddhist monasteries. In the seventeenth century, however, according to Robert Knox, measuring time with the sinking bowl had become the exclusive privilege of the king:[56]

> They have no *Clocks*, *Hour-glasses*, or *Sun-Dials*, but keep their time by guess. The King indeed hath a kind of Instrument to measure time. It is a *Copper Dish* holding about a Pint, with a very small hole in the bottom. This Dish they set a swimming in an Earthen Pot of water, the water leaking in at the bottom till the Dish be full, it sinks. And then they take it out, and set it empty on the water again, and that makes one *Pay*. Few or none use this but the King, who keeps a man on purpose to watch it continually.

But in later times, sinking bowls appear to have been used even outside the royal palace. The Pitt Rivers Museum, Oxford, owns a specimen from Sri Lanka that must have been made at the end of the nineteenth or the beginning of the twentieth century (Figure 13).

Myanmar For Myanmar (Burma), fortunately, a sinking bowl exists which was used at the emperor's palace in the nineteenth century (Figure 13) as well as a description by John Nisbet:[57]

> Each day was under Burmese rule divided into sixty hours (*Nayi*), and subdivided into eight watches, each of about three hours, which varied in length at different seasons of the year according as the days and nights were relatively longer or shorter. The *Nayi* or 'time measurer' was a copper cup having a tiny perforation at the base, which, being inserted in water, sank to a particular mark within a given time. . . . As each *Nayi* was thus measured off a gong was beaten, and at every third hour the great drum-shaped gong was sounded from the *Pahózin* or time-keeper's tower within the inner precincts of the royal palace at the eastern gate. One beat of the drum denoted nine o'clock in the morning or evening, two beats twelve o'clock, three beats three o'clock, and four

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[50] Hinüber 1978, 224–5.

[51] On *Qanāts,* see Wulff 1966, 249–56; Wulff 1968.

[52] Wulff 1966, 254–6.

[53] Glick 1969, 425–6.

[54] Thurston 1907, 563–4.

[55] Aubriot 2004, 175–82. I owe this information to Dr Jérôme Petit, Paris.

[56] Knox 1681/1995, 111.

[57] Nisbet 1901, II, 288–289.

> beats six o'clock. From Pahó the beats were repeated on large bells by all the guards throughout the palace. . . . Now, under British rule, wherever there are jails, police stations, treasury guards, and so forth, the hours are marked off by beat of a gong. Hence, in towns, the word *Nayi* has now come to mean both the hour, measured by the European method, and the clock or watch by which it is measured.

The sinking bowl in Southeast Asia

There can be no doubt that the sinking bowl spread eastward from India, in some cases with Indian terminology. In Indonesia, there is a considerable influence of Sanskrit language and Hindu religion in the islands of Java and Bali. Consequently, many Indian units of time measurement have been absorbed there, as reported by Lewis Pyenson:[58]

> Indian astronomy was certainly present in Old Javanese texts of Brahman inspiration dating from the ninth and tenth centuries. The Indian time units of day and night—divasa for 24 hours; muhurta, ksana for 48 minutes; ghati, ghatika, nadi, nadika for 24 minutes; kala for 48 seconds—all are present in the language. In Old Javanese poetry composed in Indian meter, however, the natural day is divided into equal parts of 8 hours, calculated from sunrise to sunset. The word for 'hour' is also that for 'stroke' or 'fall', suggesting hours being signalled by a striking device.

Aside from time measurement, the sinking bowl was also used in Bali for timing cockfights, which formed part of the ritual of exorcising evil spirits.[59] In Thailand, by contrast, cockfights were held to commemorate the victory of the Siamese prince Naresuan over a Burmese prince in a legendary cockfight in the second half of the sixteenth century. The duration of this fight was also determined by the sinking bowl water clock.

In China, although the prevailing water clock was the inflow type with a series of water tanks, according to Needham, the sinking bowl type was also known:[60]

> The Chinese also knew another archaic device, the inverse variant of the outflow clepsydra, a floating bowl with a hole in its bottom so adjusted that it took a specific time to sink. . . . A Chinese example is afforded by the work of the Thang monk Hui-Yuan, who arranged a series of lotus-shaped bowls to sink one after another during the twelve double-hours.

THE INTRODUCTION OF EUROPEAN HOURS

It has already been shown that from the fourteenth century onwards the Muslim rulers in India adopted the local system of measuring the equal intervals of *ghaṭī* and *pala* and also the variable intervals of *prahara* with the water clock, broadcasting these intervals with the gong called *ghaḍiyāl*. At the same time, they also continued their traditional practice of using **unequal hours** (*al-sā'āt al-zamāniya* for their prayer times, and **equal hours** (*al-sā'āt al-I'tidāl*) for astronomical purposes. But these hours, temporal or equal, did not spread beyond the Muslim community until the advent of the Europeans.

Realizing that the Portuguese and the Dutch were making huge profits from the trade with the 'East Indies', some English merchants formed the East India Company to trade with India and received a charter for this purpose from Queen Elizabeth in 1600. They sent embassies to the Mughal court, seeking license to establish trading posts in India. The presents these envoys carried to the Mughal court included mechanical clocks. Thus, Sir Thomas Roe, the Company's envoy to the Mughal Court at Agra 1615–19, presented a clock to Emperor Jahāngīr. Sir Robert Shirly is said to have presented a silver clock to him in 1616. In the same year, Shāh Abbās of Iran sent an embassy to Jahāngīr with many gifts, which included five European clocks. However, Jahāngīr, although he was interested in astronomy and technical innovations, did not mention the gift of European clocks in his memoirs. Other Europeans also made gifts of clocks to different members of the Mughal nobility. Apparently, these mechanical devices did not arouse the interest either of Jahāngīr or of his courtiers. One of the reasons for the lack of interest may be that these clocks showed time according to the European style of 12 × 12 hours, starting from midnight and midday, and not according to the Indian style of 60 *ghaṭīs*.[61]

The English trading posts, 'factories', must have possessed clocks and made use of them, but these had to be imported from England. Using the local water clock and the gong was more convenient. In his *Geographical Account of Countries Round the Bay of Bengal, 1669 to 1679,* Thomas Bowrey narrates that many wealthy Muslims set up water clocks in their front porches with two servants attending all the time, one to lift the bowl and set it up again, the other to strike the gong, and that this custom was emulated by the English and Dutch in their factories.[62] It is quite likely that in these factories, the hole of the bowl was adjusted to measure half an hour or a full hour and that European hours were announced with the gong.

In the course of the next two centuries, the East India Company, supported by a large army, gradually expanded its trade and political power so that by the middle of the nineteenth century it ruled large parts of the Indian subcontinent. In 1858, the British

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[58] Pyenson 1998.

[59] Eiseman 1990, 240–50.

[60] Needham 1959, 315 and note h.

[61] Qaisar 1982, 64–9.

[62] Qaisar 1982, 68.

Crown assumed direct control of the subcontinent, and continued the Company's practice of measuring time with the water clock and announcing the passage of European hours from all their offices and institutions. In the late nineteenth century, water clocks were progressively replaced by pendulum clocks, but announcement of the hours continued.[63] Thus by the beginning of the twentieth century, the traditional system of *ghaṭīs* of twenty-four minutes was completely replaced by the European hours of sixty minutes.

Public clocks also contributed to the dissemination of European hours, at least in some of the larger towns. The earliest public clocks were set up in churches. As early as 1516, a public clock was attached to the Church of St Francis at Cochin in Kerala. In 1660, the Basilica of the Holy Rosary was constructed along with a clock tower in the Portuguese settlement at Bandel in Bengal. Later, clock towers were also set up by administrative and secular institutions, either incorporated in their main buildings or as free-standing structures.[64]

Some sundials were also set up, with horizontal dials and triangular gnomons, resembling the *Palabhā-yantras* in design, but with lines to measure hours which are numbered either in Roman numerals or in modern international numerals. But these played only a marginal role in timekeeping and the dissemination of European hours. With increasing use of European hours, however, trade in mechanical clocks increased. British and Swiss companies began to export public clock movements, wall clocks for offices and private homes, alarm time pieces, and wrist watches. They also manufactured clocks and wrist watches specially for use in India, with the emblems of the maharajas or with pictures of tigers or of elephants, or which showed time in *ghaṭīs* and *palas*.

The Benares College founded by Jonathan Duncan of the East India Company in 1791 (now Sampurnanand Sanskrit University) owns a clock which shows time in European hours as well as in Indian *ghaṭīs* (Figure 14). It was manufactured by the Synchronome Company, London, in 1951. The dial carries four graduated scales. The innermost scale is divided into twenty-four hours and every second hour is numbered in Roman numerals from II to XXIV, with the label HOUR written below. The next scale is divided in sixty *ghaṭīs* and every second *ghaṭī* is numbered in 'English numerals' from 2 to 60, with label GHATI below. The third scale is also divided into sixty parts, but not numbered. The label below reads PALA, but *palas* (= twenty-four seconds) cannot be measured on this scale. The outermost scale is also divided in sixty parts; here every second unit is numbered in red in English numerals. The label below reads VIPALA, but again the units of *vipalas* (= twenty-four thirds) cannot be measured on this scale. In other words, all the three outer scales are divided into sixty units and can measure only the *ghaṭīs*. The labels PALA and VIPALA may have been added for didactic reasons. Surprisingly, there is no scale to measure the minutes.

The dial is equipped with three hands. The shortest one, which is reticulated, reaches up to the scale labelled GHATI; the next one, lance-shaped, reached up to the scale marked PALA; the third and longest one, painted red, reaches up to the outermost scale named VIPALA. What these three hands actually show is not known as when I saw the clock in 1991, it was not functioning.

Clock-making on a commercial scale does not appear to have commenced in India until the middle of the twentieth century, but there were individual clockmakers who repaired foreign clocks and watches and sometimes even produced innovative pieces. One such person is B. Mulchand who created a large astronomical clock for the Maharaja of Benares in 1872. This clock shows the hours and minutes according to the European fashion and *ghaṭīs* and *palas* in Indian style, but English months and dates. It strikes hours, half hours, and quarter hours. There is a separate dial to indicate the times of sunrise and sunset in hours and minutes and the Sun's position in the zodiac in signs and degrees. Another dial displays the phases of the Moon and the lunar days (*tithis*). Yet another dial shows the name of the weekday and an image of the planetary deity after whom the day is named. It also shows the ascendant and other astrological parameters.[65] This clock is now displayed in the museum of the Maharaja's palace. When Albert Edward, Prince of Wales (the future Edward VII), visited Benares on 5 January 1876, the Maharaja presented him with a smaller version of this astronomical clock, which is preserved at his seat at Sandringham.[66] One other astrological clock made in Gujarat in 1850–1 is known; a set of seventeen detached parts of it have survived and these are in a private collection.

INDIAN STANDARD TIME

Even though the European hours were adopted by the beginning of the twentieth century, there remained a major problem. Every city followed its own local time based on the mean sunrise and sunset. John Goldingham, the first official astronomer of the Madras Observatory, determined, on the basis of his observations of the eclipses of the satellites of Jupiter made between 1794 and 1802, the longitude of Madras at 80° 18′ 30″, corresponding to 5 hours 21 minutes and 14 seconds ahead of Greenwich Mean Time.[67] This came to be known as 'Madras Time'. By the late 1860s, railways and telegraphic communications expanded rapidly, and telegraphs began to use 'Madras Time' uniformly

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[63] This practice continues even now. Between 1974 and 1981, the author lived in a house in a north Indian town where he could hear the regular announcement of the hours from the district jail as well as from the office of the district collector.

[64] In his forthcoming work on the clocktowers of India, Debasish Das describes some 120 clock towers erected during the colonial period.

[65] Sen 2015, 170–1; Sarma 2019a, 4081–5.

[66] Sarma 2014. Our thanks to Rufus Bird, Keeper of the Royal Collections, for locating the clock (RCIN 7810).

[67] Anon 1809.

Figure 14 Synchronome clock with a dial for hours and *ghaṭīs*. Photos: S. R. Sarma.

in all their dispatches.[68] The Railways adopted 'Madras Time' as their standard time in 1870 and began publishing their timetables accordingly, with the result 'Madras Time' began to be called 'Railway Time'.

In 1904–5, the Royal Society recommended to the colonial government to divide the country into two time zones, fixing the time at six hours ahead of the GMT in the east and five hours in advance of the GMT in the west, but this recommendation did not find favour with the government, who desired a single time zone for the entire subcontinent.[69] The government replaced Madras Time of 5 hours, 21 minutes, and 14 seconds by a more convenient period of 5 hours and 30 minutes in advance of the GMT and declared the meridian passing through the longitude 82° 30′ E as the central meridian for India. This Indian Standard Time came into effect at midnight 1 July 1905.[70] It was immediately adopted by all the major railway companies and all government offices. However, there was strong resistance in Calcutta, which was proud of being the capital of British India, and also in Bombay, the industrial and commercial metropolis, and these two cities retained their local time. After India attained independence from British rule in 1947, the government established Indian Standard Time as the official time, but Calcutta and Bombay followed their local times until 1948 and 1950, respectively.

WATER CLOCKS AT PLACES OF WORSHIP

Even after the *Ghaṭikā-yantra* was replaced by European clocks, the former continued to be used for ritual purposes in the places of worship of all major faiths in the Indian subcontinent. On the day of *Janmāṣṭamī*, the birth of the Hindu god Kṛṣṇa is celebrated at all the temples of Mathura (27° 30′ N, 77° 40′ E) in Uttar Pradesh. The festivities commence at midnight when Kṛṣṇa is supposed to have been born. At the Dwarakadhish temple, the precise time of midnight is said to be determined by means of the water clock. At the Jain temple dedicated to Tirthankar Shantinath at Jhalawar (24° 35′ N, 76° 10′ E) in Rajasthan, the *Ghaṭikā-yantra* is still used to determine the time of various rituals.[71] In the town ofSehwan in Sindh, Pakistan, at the mausoleum of Qalandar Shahbaz, the water clock was in use as late as 1973 for determining

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[68] Krishnan 2013, 47

[69] Krishnan 2013, 33.

[70] Krishnan 2013, 78.

[71] Reported in *The Hindu*, New Delhi edition, 24 April 1994; cf. Sarma 1994; this water clock was shown in the BBC TWO documentary series *What the Ancients Did for Us*, Episode 5: 'The Indians', broadcast on 5 March 2008.

Figure 14 detail.

the times of prayer and the time of the dance of the dervishes (*dhammal*).[72]

SUNDIALS AS URBAN SCULPTURE

Sundials also have not been completely forgotten. Following European fashion, a few large sundials have been set up as urban sculptures in public places. A notable specimen is a sundial in the shape of the *Palabhā-yantra* set up recently near the Barapullah Flyover in New Delhi by the Delhi Development Authority. The brass gnomon has a height of 12.7m and a length of 24.5m. The hour lines are laid out in coloured marble and numbered in large Devanagari numerals.[73]

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[72] Baloch 1979.

[73] Information from Debasish Das.

SECTION TWO: CHINA TO 1900

David Chang

'Respecting the heavens and giving time' was a core idea of ancient Chinese civilization.[74] Firstly, astronomy is the major attribute of Chinese imperial rule—observation and forecasting of astronomical phenomena was the first task of the Emperor. Secondly, in order to maintain power, the dynasty had to promulgate time rules with the calendar at their centre. The system of ancient Chinese astronomy had been established before CE 220.[75] Since the primary interest of this discipline was political, research was accorded official support. Making various astronomical instruments was one important task, and this included the manufacture of time measurers, timekeepers, and mechanical astronomical timepieces to assist observations. The time frame of the calendar determined the units of measurement. The year, month, and day are all time units from nature. Their periods can be determined through astronomical observations. As the 'day' has the shortest period and can be intuitively perceived, it was the basic time unit in ancient China.[76] Faced with astronomical changes, the Chinese formed a unique concept of cyclical time. The Chinese characters, represented by ten heavenly stems and twelve earthly branches, cooperate with each other and are shown by a pair of stem branches every day, with the sixtieth day as a cycle, which constantly repeats.[77] In order to divide the **nycthemeron**, the Chinese adopted three main systems (Figure 15): twelve 'double hours', 100 'quarters', and five 'night watches'.[78]

CHINESE TRADITIONAL TIMEPIECES

The Chinese official Xue Jixuan (CE 1134–73) mentioned four types of timepieces in his book: the **sundial**, the incense stick, the rolling ball, and the **water clock**.[79] Among these typical ancient Chinese timekeeping devices, only the sundial is a time finder.[80] Records are preserved in Chinese literature of work with gnomons concerning the Sun's azimuthal position as a function of time from CE 102 and CE 594.[81] Later, it was realized that for the scale to be evenly divided, the dial needs to be set parallel to the celestial equator, with the gnomon directed towards the celestial pole. This is the equinoctial sundial, the type most commonly used in ancient China. It appeared no later than CE 851.[82] The territory of the Southern Song Dynasty (1127–1279) was dominant south of the Yangtze River, at which time the equatorial sundial appeared in various cities and became popular.[83] Until the Qing Dynasty (1644–1911), this kind of sundial was placed outdoors in government offices and palaces. Although the sundial can only be used during the day, when there are no clouds or rain, of the four types of timepieces it was the most popular. Around CE 1612, the Spanish missionary Diego de Pantoja (1571–1618) and Sun Yuanhua (1581–1632) collaborated in writing a book in Chinese, recording various Western sundial manufacturing methods.[84] Since then, the Chinese have not stopped studying Western sundials, and the use of portable dials is also very common.

The incense stick is the most common timekeeper in popular use because of its low cost and simplicity. The solid incense baton includes straight lines, circles, and Chinese characters. Time is displayed by the burning position. An inscription from CE 1073 records that there were not only incense sticks that showed the twelve 'double hours' and 100 'quarters', but also sticks dedicated to the night showing the five 'night watches'.[85] The incense powder was formed into various patterns using a mould, and the patterns could also be timed after the incense trail was ignited. The date and origin of these methods are unknown, but they were probably known from the eighth century CE, becoming popular

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[74] Ruan 1935, 2. In 1799, Ruan Yuan (1764–1849) completed a biography of a Chinese scientist in which he noted that the most important task for the emperor was to effect astronomical observations.

[75] Jiang & Niu 1998, 19–21.

[76] There are twelve months in a year and twenty-nine or thirty days in a month since the ancient Chinese calendar combined the solar year and the lunar month. In order to coordinate the number of days between the two methods, in every determined period two consecutive months will be thirty days, and there will be thirteen months in a given year, see Zhang 2019, 82–6.

[77] Ten heavenly stems: 甲乙丙丁戊己庚辛壬癸. Twelve earthly branches: 子丑寅卯辰巳午未申酉戌亥.

[78] See this volume, 'Introduction'; Needham, Wang, & Price 1986, 199–205.

[79] Xue 2003, 446.*The New York Times* 18 July 1875 recorded that the Chinese were still then using the sundial, the incense stick, and the water clock; see Zheng 2001, 88.

[80] For dials in general, see Chapter 1, Chapter 3, Section 1, and Chapter 8. In ancient China, the equinoctial direction dial used the twelve earthly branches as the scale of the dial, and the gnomon passed vertically through the centre of the dial. The top face of the dial was used for the summer period from the spring equinox to the autumn equinox, the lower face for the winter period from the autumn equinox to the spring equinox.

[81] Needham 1959, 306; Quan 2013, 379.

[82] Wang 1986, 8.

[83] Quan 2013, 379–80.

[84] Fung, 2004, 348–9. The book title is *Sundial Diagram* 日晷圖法.

[85] Wang 1989, 260–1.

Figure 15 Correspondence between the twelve 'double hours' and twenty-four hours.

during the Northern Song Dynasty (960–1127). The most useful form was perhaps the dragon boat clock (Figure 16) in which an incense stick was laid lengthways along the body of a holder in the form of a dragon boat. Cords, with small bronze weights at each end were hung across it at appropriate positions so that as the stick burned along its length, they would fall, giving an aural indication of the hour, on a metal platter below. By placing only one weighted cord in a predetermined position the device could also act as an 'alarm clock'.[86]

The rolling ball was invented by a monk in the Tang Dynasty (618–907). This is a very simple timepiece that uses a bevelled track made of bamboo or wood. A ball is placed on it to roll down under the action of gravity. It records time from the accumulated number of the descents which occupy equal intervals of time. As this relies on manual control, it cannot guarantee timing accuracy. Because it can be used at any time, and anywhere, rolling balls were generally used when travelling and marching, at least until the Yuan Dynasty (1271–1368).[87] Obviously, neither this, nor the incense timepiece, was used in astronomy.

Figure 16 A dragon-boat incense timepiece. Photo: Courtesy of Macau Timepiece Museum.

Among the four types of timepieces, the water clock is the oldest and the most widely disseminated. It was used for astronomical timekeeping during the Western Han Dynasty (206 BCE– CE 8), using the change in water level caused by its flow into or out of

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[86] Needham 1959, 330. A far more detailed account is given by Bedini 1994a.

[87] Dai 1988, 268–9. Guo 1988, 182–3. Needham's understanding of the rolling ball timer as a spring device is wrong; he was misled by Ruan Yuan's writings. See Needham 1965, 527.

Figure 17 Lu Cai's inflow type clepsydra with are three compensation tanks. (top) Yan Su's inflow type clepsydra, has an overflow tank on the ground. (bottom) Illustration from Liu Jing Tu Kao 六經圖考 of Yang Jia (c.1110–84), reprinted in 1722, Book vi 37.

a container to display the time.[88] To maintain a constant speed of flow for inflow type clepsydras overflow tanks were introduced to ensure a constant head of pressure. A famous example in this regard is the work of official Lu Cai (b. ?–CE 55) (Figure 17, top). The official, Yan Su (CE 961–1040), designed the overflow tank in CE 1030 (see Figure 17, bottom). Shen Kuo (CE 1031–95) then improved this design and the accuracy of the instrument.[89]

The advantage of the water clock is that it can be used during both day and night, and it shows subdivisions using the 100 'quarters' system. In addition to its applications in astronomical work, different types of the instrument were in popular use. The most accurate was the steelyard **clepsydra**. It displayed time using the principle of equalizing the weight of dripping water per unit time,[90] but it is an intermittent timepiece that cannot display the time continuously and has uses similar to those of a 'stopwatch'. This timepiece was invented by Li Lan (*fl.*450) in the fifth century CE. At first it was a small device, then a large one was made for the emperor by the officials Yu Wenkai (CE 555–612) and Geng Xun (CE ?–618) in about CE 605. From the Sui Dynasty (581–618) to the Tang and the Northern Song Dynasty, the steelyard clepsydra was the main astronomical timepiece of the imperial family.[91]

ASTRONOMICAL TIMEPIECES FROM THE SECOND TO THE THIRTEENTH CENTURY

The history of Chinese mechanical timekeeping begins with astronomical timepieces. About CE 130, the first astronomical timepiece was made by the official Zhang Heng (78–139): a celestial globe driven by water. In addition to the celestial globe running once a day, the mechanical transmission could also display the number of days in the lunar month (similar to a calendar mechanism).[92] But there is no detailed description of the power and control devices in the literature concerning this timepiece.[93] About an astronomical timepiece by Geng Xun, the text clearly states that it was not only rotated by water, but also 'required no manpower'. In order to achieve such independence, some kind of control device was certainly used.[94] Although a clear answer cannot be given as to what it was, water power was clearly traditional in Chinese astronomical timepieces. These prototypes of the mechanical timekeeping that appeared in China in the second century CE laid the foundation for the development of later Chinese astronomical timepieces.

In the 600 years after Zhang Heng, these became increasingly complex.[95] The astronomical demonstration is more intuitive and the timing function is more prominent, which meant that Chinese mechanical timekeeping had matured. The astronomical timepiece made by the scholar Yi Xing (683–727) and the official Liang Lingzan (*fl.*721) in CE 725 was a turning point. It added sun and moon motions to the celestial globe. The transmission was further complicated: as there were two wooden jacks, one striking a bell to indicate the hours, and the other striking a drum to indicate the quarters.[96] Henceforward audible time-announcement became standard in Chinese mechanical timepieces. However, the power and control devices designed by Yi Xing are still not clearly described.

A somewhat more detailed record appears in the introduction to astronomical timepieces by Zhang Sixun (*fl.*976).[97] This astronomical timepiece completed in CE 980 indicated the quarters

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[88] Chen 2016, 1247–50. Hua 1991, 22–4. water clocks are mainly divided into two types: **outflow** and **inflow**. The **outflow** type is the earlier, but the use of the **inflow** type was more popular.

[89] Hua 1991, 61–4, 84–94. The scales used by Shen Kuo's clock could also display the five 'night watches'; see Guo 1988, 96.

[90] The water weight unit is converted into a time scale, which is displayed directly on the weighing rod. The siphon is used to stabilize the water flow, ensuring the equal weight of the water flow in equal time.

[91] Hua 1991, 65–7.

[92] Mechanical transmission relies on gears. Before Zhang Heng, gears had already been used in China, see Needham 1965, 85–8. For research on calendar mechanisms, see Liu 1962, 116–19.

[93] Scholars have conjectured; see Liu 1962, 99, Figure 115. Li 2014, 81, figs. 1–45. Needham, Wang & Price 1986, 112, fig. 3.3.

[94] This astronomical timepiece was made around CE 590, see Needham 1965, 482. Considering Geng Xun's familiarity with the steelyard clepsydra, it is likely that he used the principle of leverage as a control device.

[95] For the development of astronomical timepieces from Zhang Heng to Geng Xun, see Needham 1965, 482–4; Forte 1988.

[96] Needham 1965, 473–4.

[97] Needham 1965, 470–1. The instrument uses mercury instead of water as the power source, thereby eliminating the problem of water freezing. However, the physical properties of mercury pose their own problems, see Guo 2011, 475–6.

audibly (seven jacks strike different instruments), and the hours visually (twelve jacks hold hour signs). Obviously, the twelve 'double hours' and the 100 'quarters' are expressed in two different ways, visual and aural, respectively. This was the first large astronomical timepiece in the Northern Song Dynasty, which, by adopting a more complex gear system and control device, allowed Chinese mechanical timekeeping to reach its summit. In CE 1092, led by the officials Su Song (1020–1101), Han Gonglian (*fl.*1088), and others, a great astronomical timepiece, called Shui Yun Yi Xiang Tai 水運儀象台, was completed.[98] In addition to the devices for driving the armillary sphere and the celestial globe, the mechanical design is outstanding. It includes a driving water wheel with a weighing-rod timing device, linkwork control devices, gear transmission devices, and time display. A new mechanism also appeared in this instrument. This was a water wheel and steelyard clepsydra mechanism, which consisted of a timing steelyard clepsydra and a water wheel lever. The former was used to generate uniform and periodic motion, and the latter to generate periodic vibration to check and release the intermittent motion of the water wheel.[99]

The time display device is located in a wooden pavilion of five stories with different wooden jacks on different levels. These jacks can display all three Chinese horary systems: the twelve 'double hours', the 100 'quarters', and the five 'night watches'. They also indicate the quarters of each hour and the night watches by striking different instruments.[100] The entire astronomical timepiece is located in a building about 12m high (see Figure 18). The armillary sphere is placed on the upper floor, the celestial globe is placed on the middle floor, and the wooden pavilion is placed on the lower floor. Chinese mechanical timekeeping had reached a new stage of development. Following a change of dynasty, this timepiece was moved to Beijing in CE 1127, but after a few years only the device for observing astronomical phenomena survived. It was damaged by lightning in CE 1195. After the Mongols overran Beijing in CE 1214, the remaining parts of the astronomical device disappeared.[101]

Su Song's astronomical timepiece is the most complicated mechanical timekeeping device known from ancient China. It combines the three major functions of observation, demonstration, and timekeeping. The 'escapement' that appeared in the timekeeping machine has been claimed as 'an intermediate stage or "missing link" between the time-measuring properties of liquid flow and those of mechanical oscillation'.[102] Whether this had any direct influence on European timepieces remains uncertain,[103] but, in the history of world mechanical timepieces, especially before the appearance of the solid weight-driven timepiece, it does provide a vivid example of the fusion of the motor, distribution and oscillator systems In fact, the value of Shui Yun Xi Xiang Tai goes far beyond the scope of a timepiece. From this huge machine, we can deduce many concepts such as tracking observation, power gear, and *remontoir*.[104] This machine occupies a very important place in the world history of precision technology.

If the mechanical clock was a 'fallen angel' from the astronomical world,[105] then several 'angels' appeared in the Yuan Dynasty (1271–1368). These were rather more independent of astronomy. They are still driven by water power but are more focused on automata display.[106] In CE 1276, the official Guo Shoujing (1231–1316) designed a mechanical timepiece for the Imperial Palace and used a hydraulic display device for the first time to show the quarters on a rotating ring against the finger of a jack.[107] The last emperor of the Yuan Dynasty (r. 1333–68) had a similar mechanical timepiece made in CE 1354, but the structure was more complicated. It employed many kinds of automata, jacks, and animals, which performed at the specific times required.[108]

After the establishment of the Ming Dynasty (1368–1644), officialdom no longer attached importance to the construction of mechanical timepieces, but civil research and innovation continued. The most famous example is the work of Zhan Xiyuan (*fl.*1370), recorded by the official Song Lian (1310–81).[109] His timepiece is different from those made previously and has become a simple timekeeper. It has two main features. Firstly, dial and hand are used to display the time.[110] Secondly, the driving wheel is moved by sand and power is transmitted through five

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[98] In CE 1096, Su Song completed *New Design for an Armillary and Globe* 新儀象法要, which was the first and most detailed monograph on astronomical instruments in China, and a scientific and technological work of world significance. The astronomical is introduced and illustrated in this book.

[99] Yan 2007, 176–82.

[100] Needham, Wang & Price 1986, 34.

[101] Needham, Wang & Price 1986, 132–3; Dai 2010, 370. Many scholars participated in the research and restoration of this timepiece, see Zhang & Zhang 2019, 47–55.

[102] Needham, Wang, & Price 1986, 59. From the analysis of words and images, this timepiece certainly had a mature control system although this is different from that employed in European weight-driven clocks. Needham believed that water wheel linkwork mechanisms were first used by Yi Xing, see Needham 1965, 474, note c. Dai believed it was by Zhang Sixun, see Dai 1988, 52–3. Wang believed it was by Su Song; see Wang 1989, 273.

[103] Landes 2000, 18–20.

[104] More information about this machine in Needham, Wang, & Price, 1986.

[105] Price 1975, 369. Lu, however, denies mechanical clocks to be by-products of astronomical instruments, and thinks their development paths were different, see Lu 2017, 65–70.

[106] Since Yi Xing's astronomical timepiece, the tradition of using jacks has not changed, and it has continued in Chinese clockmaking.

[107] Guo 2011, 524–5. Needham, Wang & Price 1986, 135–6.

[108] Needham 1965, 507.

[109] Song 2014, 2193. Needham, Wang & Price 1986, 158–9.

[110] Needham 1965, 512, fig. 668. This is the same display as the European mechanical clock of the same period. This timepiece still uses the jacks to tell time.

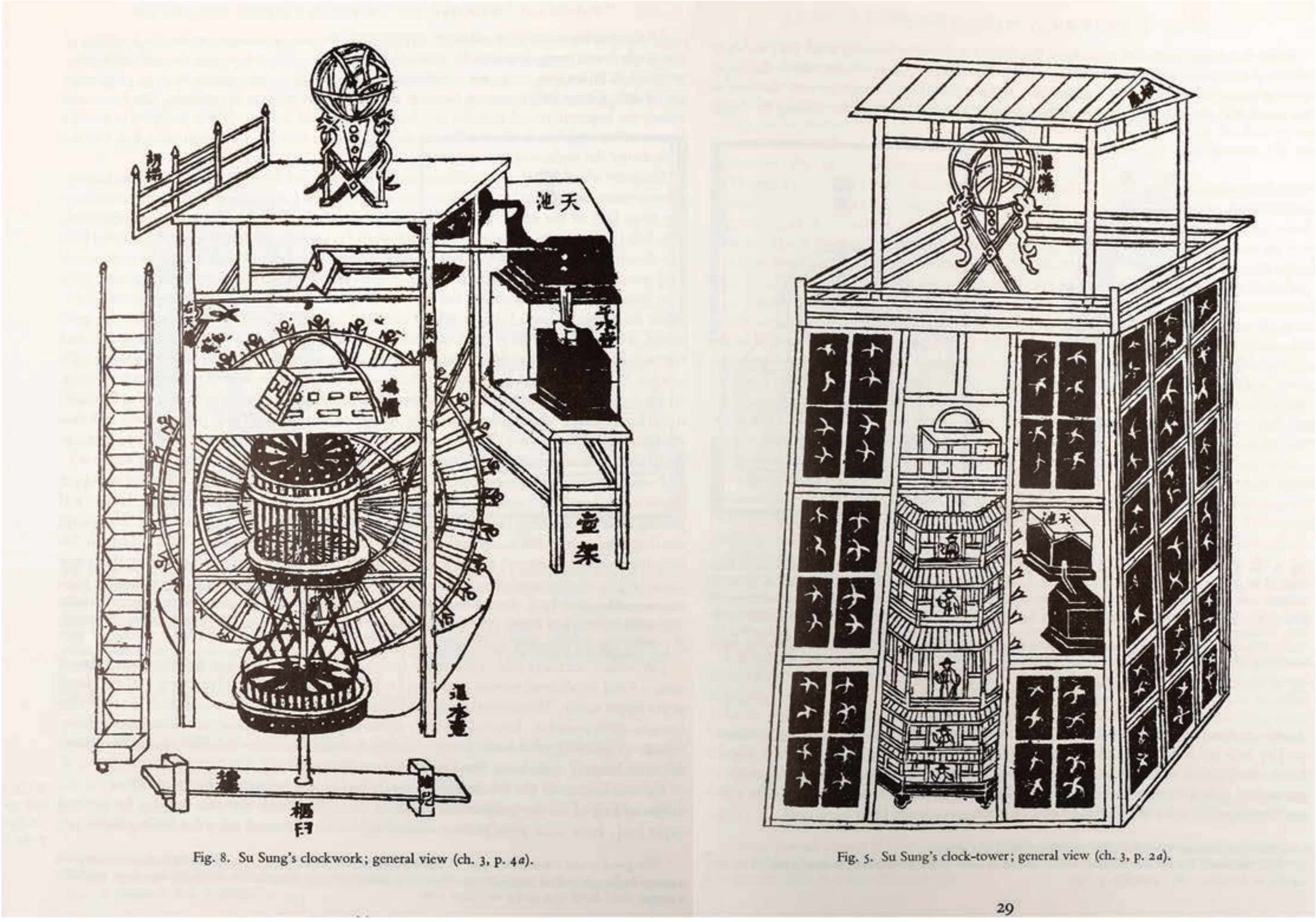

Fig. 8. Su Sung's clockwork; general view (ch. 3, p. 4*a*).

Fig. 5. Su Sung's clock-tower; general view (ch. 3, p. 2*a*).

Figure 18 Su Song, *New Design for an Armillary and Globe*, Chapter iii, 85, 89. (a) Exterior; (b) interior. Photo: Jean-Baptiste Buffetaud.

gears.However, compared with water flow, the controllability of sand flow is not ideal. Two hundred years later Zhou Shuxue (mid-sixteenth century) made a series of improvements to it.[111] From the water clock to this piece, after more than 1,000 years of development, Chinese timekeepers seemed to be entering a more modern phase. At the same period, however, the history of independent timepieces in China was reaching an end. European missionaries brought weight- and spring-driven clocks to China and the development of Chinese timepieces became involved with that of Western clocks.

THE INTRODUCTION OF EUROPEAN CLOCKS

From the middle of the sixteenth century, Jesuits priests preached in the Far East, introducing weight- and spring-driven clocks to Japan and China as concomitant to their endeavour.[112] We cannot know how many clocks the missionaries donated or made in China in the twenty years from 1581 to 1601, beginning with Michele Ruggieri (1543–1607). But it is certain that Macao was the starting point for missionary 'horological diplomacy' in China. Luxury clocks brought by Jesuits or shipped from Europe would be collected in Macao and would play an important role.[113] When the missionaries wished to live in Zhaoqing, in mainland China, the clock was a gift to Chinese officials that eased the way, as they were curious about it and liked it. In September 1583, the missionary Matteo Ricci (1552–1610) arrived in Zhaoqing, and from there began a seventeen-year attempt to reach the Ming Dynasty capital in Beijing. The following year Ruggieri sent him the best clockmaker in Macao: 'a Canary Islander who had come from India, black-skinned' to make a clock for the Zhaoqing prefect Wang Pan (fl.1580).[114] Ricci carried clocks to Shaozhou (1589), Nanchang (1595), and Nanjing (1598), displaying or giving them to local officials. Knowledge of European clocks was thus spread.[115] Ricci had realized that, for the Chinese, Western clocks

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[111] Bai & Li 1984, 140.

[112] Bedini 1975, 454–8. In CE 1581, Ruggieri gave a clock to an official in Guangzhou, see Bernard 1936, 190. For a comparative perspective, see Hiraoka 2020.

[113] Chang 2020. 'Horological diplomacy' is a very vivid term, see Jin & Wu 2007, 538.

[114] Spence 1984, 184.

[115] Tang 2012, 291–2.

and watches were very special, and that such gifts could be used to build close relationships with the upper classes in China. As a result, he not only established friendships with Chinese officials, but also spread Catholicism to them. Famous Chinese Catholics included Xu Guangqi (1562–1633), Li Zhizao (1571–1630), and Yang Tingyun (1562–1627).[116]

The crown wheel escapement, foliot, and mainspring or weight-driven mechanisms introduced into China were completely different from the prevailing types of mechanical timepieces there. This made the Chinese curious and spread information about them; they also led some scholars to think about and accept European scientific thought.[117] In a description of gifts to the Emperor Wanli (Zhu Yijun, reigned 1573–1620) on 27 January 1601, Matteo Ricci explicitly recorded two clocks.[118] Diego de Pantoja wrote:

> When all things were put in order, particularly those that were designed for the king, there were two clocks with wheels, one large and made of iron, in a very large case, beautifully made, with multiple carved representations of golden dragons, that are the emblem of the Emperor, just as the eagle is that of the King [of Portugal and Spain]. Another, smaller, very beautiful one, one palm high, inside a golden case. The two cases were made in China.[119]

Western clocks not only entered the Chinese court for the first time, but small clocks were very much liked by Wanli. As the Chinese did not understand the operation of such clocks, the emperor sent eunuchs to learn clock technology from Ricci, whom he also needed to visit the palace regularly to maintain his clocks. It was thus that Ricci was able to live in Beijing for a long time.[120] In order to facilitate the eunuchs' education, Ricci also translated the names of clock parts into Chinese. It is worth noting that Ricci had translated or edited this work, because in the Chinese book on Western mechanics prepared by the missionary Johann Terrenz Schreck (1576–1630) in 1627, a Chinese work called *Explanations of the Clock* 自鳴鐘說 was cited as a reference.[121] Wang Zheng (1571–1644), who worked with Schreck, published a book on mechanical engineering, which included descriptions, with diagrams, of his own work. Among them was a timepiece that employs traditional Chinese visual and auditory indications but uses a European-type weight drive with foliot—an important step forward in the Chinese application of the Western escapement and oscillator.[122] This major change following the introduction of Western science by the missionaries was exactly 530 years after the publication of Su Song's astronomical timepiece.

As Western watches and clocks entered China, a 'Horological Road' formed from West to East.[123] Chinese officials and scholars both praised and criticized clocks. Praise was mainly for their timekeeping qualities. Critics thought they were useless—simply expensive. Concerning the question of the origin of clocks, some people regarded the mechanical timepieces in Chinese history as the origin of clocks.[124] When the horological trade prospered in China, they emphasized that China is a vast land, and could create inventions on its own without having to buy foreign goods.[125] From the middle of the nineteenth century, when Westerners penetrated into Qing society, clocks became contradictory objects, inspiring love and hate. On the one hand, many people were eager to purchase foreign goods as fashionable; on the other hand, some officials found foreign goods repugnant and advocated resistance. On the Horology Road, Chinese xenophobia and openness have never ceased to conflict.

Xu Chaojun (1752-1823) was both scholar and craftsman in Shanghai. He published China's first book on horological technology in 1809, covering ten aspects, with more than fifty drawings of mechanical parts.[126] This book can be regarded as a summary of the knowledge of watches and clocks before the nineteenth century. Among other topics it gave a brief description of the gearing and showed how to disassemble a mechanism. At this time, there was already a clockmaking industry in China, especially in Shanghai, and Xu's work may not have been widely distributed or read.[127] Another scholar, Zou Boqi (1819–69), also studied clocks in Guangzhou. He understood the principle of clock pendulums and realized the fundamental difference between a clock and a sundial. The clock displays mean solar time while the sundial displays true solar time, which are not the same.[128] Zou's scientific spirit

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[116] Xu and Li were particularly interested in Euclid and Clavius' *Sphaera* on which they worked with Ricci. Spence 1984, 152

[117] Li 2012, 18–19. Of course, this attraction still existed in the Qing Dynasty.

[118] This document dated to the twenty-fourth day of the twelfth month, and the twenty-eighth year of Wanli, see Zhu 2001, 232–3.

[119] Ye 2019, 408. Thanks to Fernando Correia de Oliveira for the translation from Spanish to English.

[120] Bedini 1975, 462. For a discussion of why Ricci lived in Beijing, see Jin & Wu 2007, 536–67.

[121] Korean scholar Li Guiying (1788–?) records *Explanations of the Clock* as written by Ricci; see Tang 2017, 549. This book has not been seen in China. It remains to be researched by scholars.

[122] Needham 1965, 513.

[123] In the history of Sino-Western cultural exchanges, the Silk Road has always occupied an important position, but the road of timepieces from Europe to China also deserves attention as much for the light it can cast on religion, trade, and diplomacy as on technology dissemination and ideology.

[124] Li 2012, 58–61.

[125] Li 2012, 112–13.

[126] Chen 1987, 43.

[127] Chinese artisans mainly used experience to teach, rather than systematic theoretical learning. Although focusing on practice enhanced craftsmanship, it stuck at the level of imitation and was not innovative.

[128] Zou 2009, 172. Thanks to Mr Ye Yongjian for the documentation provided.

helped the development of Guangzhou and Chinese clockmaking even if watchmaking did not develop on a large scale. On the one hand, it lacked a theoretical basis of mathematical and mechanical knowledge; on the other, it relied too much on manual manufacturing and lacked professional machinery and equipment.

MANUFACTURE OF THE IMPERIAL CLOCKS

Xu Guangqi, the friend of Ricci, not only accepted Western learning but also applied the results of Western science. When he presided over the calendar reform of the late Ming Dynasty in 1629, he suggested to the emperor that three clocks should be made.[129] This did not occur before the fall of Beijing to the Manchus and the establishment of the Qing Dynasty (1644–1911), so the ideas of Ming Dynasty officials were realized by the Qing emperors. Initially the court simply maintained its collection of watches and clocks, but clocks soon were made. In 1689, the Emperor Kangxi (r. 1662–1722) established a scientific and artistic institution in the Forbidden City. The main purpose of this was to sustain the imperial manufacture, and to facilitate Western academic activities.[130] There is no doubt that there were many workshops in this institution, including a clock workshop, which not only manufactured new clocks and modified existing ones, but also maintained, repaired, and installed those that were on display.[131]

Just as Matteo Ricci served the Wanli of the Ming Dynasty, so the principal makers of clocks for the Emperors of the Qing Dynasty were Christian missionaries. For over a century, more than ten of them—from Gabriel de Magalhães (1609–77) to Charles Paris (1738–1804)—were successively court clockmakers.[132] The Swiss Frantz Stadlin (1658–1740) served in the clock workshop from 1707 and was the first to make a pocket watch for Kangxi. In his later years, Kangxi talked about how the missionaries improved the accuracy of clocks.[133] Once technical problems were solved at court, it became possible to produce pocket watches.[134] Combining Western technology with the Chinese horary system had also always been a main focus of the workshop. On 16 October 1736, the French Valentin Chalier (1697–1747) described in a letter a clock showing the five 'night watches' that he had made. It took him four months to complete, and it could strike the unequal night watches.[135] Another French maker, Jean-Mathieu de Ventavon (1733–87), was good at creating automata. At the end of 1785, the Emperor Qianlong (r. 1736–95) ordered him to develop a figure that could write Manchu.[136] Under Qianlong, the clock workshop reached a peak, but unlike his grandfather Kangxi, Qianlong preferred to treat the clock as a mechanical toy with Chinese elements. Indeed, while European clockmakers developed highly decorative and highly precise timepieces during the eighteenth century, the Chinese imperial clocks only became increasingly artistic and adorned with automata. It was their most distinctive feature.

The imperial clock was a fusion of Chinese art and European technology, produced by Western clockmakers and Chinese craftsmen working together. Craftsmen from other workshops in such crafts as enamel, wood carving, and gilding supported the clockmakers.[137] Imperial clocks are not simply replicas of Western clocks. They have an entirely Chinese style of decoration while incorporating various types of automatic musical devices that continue the tradition of medieval Chinese timepieces. The abundance of people or animals in the clocks led to the aural and visual indication of time being neglected. The usefulness of the imperial clock as a timekeeper was not emphasized.[138] The impact of these imperial clocks was not only material, but also spiritual. Firstly, in the field of literature, members of the imperial family or central officials wrote poems or essays to introduce clocks, and expressed in these works their perception of time.[139] Secondly, clocks appeared in court paintings, shown as display items in the living room or the playthings of nobility.[140] Illustrations and explanatory texts about clocks and pocket watches appear in the imperial book of ordinances and artefacts completed in 1759.[141] This shows that, in the consciousness of the emperor, clocks and watches were not simply timepieces, but also

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[129] Xu 1963, 336.

[130] Kangxi's interest in western learning also gave the missionaries a certain position in the court, and they served as the emperor's teachers. See Yan 2015, 312–28.

[131] About the clock workshop at the court, see Pagani 2001, 37–9.

[132] Pagani 2001, 46–7. Biography of the missionary, see Guo 2011, 197–234.

[133] Kangxi 1994, 134–5.

[134] For some pocket watches made in the Kangxi period, see Chapuis 1919, 42–3. Patrizzi 1980a, 67

[135] Pelliot 1920, 64–5. The letter stated there were more than 4,000 scientific supplies such as clocks and watches from Paris and London at the Chinese court.

[136] Hou 2009, 105. *Cf.* this volume Chapter 16, n. 59 After 1750, the production of automata figures was the main task of missionaries.

[137] In addition to the clock workshop, there were dozens of workshops for making other artefacts.

[138] Cipolla 1967/2003, 87. Cipolla believes that the Chinese only regarded the mechanical clock as a toy, but he only saw one aspect. In the eighteenth century, the timekeeping function of clocks and watches was also valued, but not solely, and at that time people who could own a clock were a minority.

[139] Li 2012, 24–8.

[140] Guo 2013, 303–11. For images of some clocks that appeared in the Qing Dynasty, see Li 2014 206–15.

[141] Pagani 2001, 62.

Figure 19 Wood and enamel clock in the form of a two-storey building. H. 88cm, W. 51cm, D. 40cm. Royal clock workshop. Qianlong period. Palace Museum, Beijing. Photo: Qi Haonan.

represented a ritual instrument equivalent to those of astronomy. Was not the bell ringing every day in the court a symbol of the order of the emperor? In imperial clock manufacturing, the emperor firstly proposed his own idea, then repeatedly revised it, before the plan was finally passed to a clockmaker to be made. The function of the clock was mainly display. For some special occasions, such as the birthday of the emperor or his mother, special clocks or 'blessing automata' were made.[142] But, some were made and used for timing, such as the large striking clocks (see Figure 19), and some portable clocks fitted with an alarm function.

In the early nineteenth century, following an official ban on missionary activities, there were no longer any Europeans in the clock workshop to serve the imperial family. As the watch trade brought Swiss pocket watches to the court, these smaller, more convenient devices became popular with the imperial family. However, the clock workshop lacked watchmaking talents, and craftsman could not fulfil imperial requirements for pocket watch manufacture.[143] More importantly, the new emperor, Jiaqing (r. 1796–1820), the son of Qianlong, lacked his father's interest. He did not like decorative clocks and automata, only practical timepieces. The imperial clock workshop was bound to decline.[144]

TRADE INPUT AND THE IMPACT OF POCKET WATCHES

For China and Europe the eighteenth century was an era of trade development.[145] In 1757, Qianlong decided that all Western trade would be concentrated in one port, Guangzhou. Missionaries had used clocks to open China's doors to themselves 175 years earlier, and now clocks were one of the several goods that European merchants used to reduce the amount of silver bullion needed to pay for the tea and other Chinese goods desired in Europe that stimulated trade during the Qing Dynasty.[146] By the middle of the eighteenth century, the English East India Company brought mechanical clocks worth more than £20,000 from London to Guangzhou each year.[147] In 1791, before the British ambassador George Macartney (1737–1806) visited China, the number of 'Sing-songs' recorded by the Guangdong Customs reached 1025 pieces.[148] After visiting the Chinese palace in 1793, Macartney

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[142] Pagani 2001, 40–1. Hou 2009, 108–9.

[143] Chapuis 1919, 40.

[144] Guo 2011, 171.

[145] In the late Ming Dynasty, the Portuguese had begun trade with China. Later, the Dutch, the British, the French, the Danish, the Austrian, and the Swedish all participated; see Zhang 2019, 473–9.

[146] European missions with commercial purposes also gave clocks to the imperial family as gifts, but most clocks entered China through trade routes.

[147] Braga 1967, 69. The English East India Company (1600–1874) had focused on trade in Guangzhou since 1716, and Britain had become a major trading country with China by the 1750s at latest.

[148] Guan 2000, 88.

thought that the clocks and watches there were all made in England.[149] The British were indeed at the forefront of the clock trade, benefiting from an advanced clockmaking industry, and an advantageous trade position with China.[150]

In the Sino-British horology trade, the works of two British families, Cox and Ilbery, are representative. James Cox (1723–1800) entered the Chinese market in the mid-1760s. His goods were characterized by an extravagant appearance and incorporated dynamic automata and musical functions in a Chinese style born of Western imagination, although this did not weaken Chinese enthusiasm for them,[151] and English clocks, to a certain extent, formed a technical interaction with the manufacture of imperial clocks. Following Cox's bankruptcy in 1778, partly caused by payment failure in China, his son John Henry Cox (*c.*1750–91), went to Guangzhou in 1781 to recover debts and continue to trade in watches, clocks, and other goods.[152]

By the 1780s, the watchmaker John Ilbery (1750–1808) had a well-established business into which he later incorporated two of his sons: William Ilbery (1772–1852) was in charge of the business in London, and James Ilbery (1784–1839) was in charge in Guangzhou.[153] They developed a typical 'Chinese Market Watch', in association with Swiss makers.[154] They used the French Lépine calibre (Figure 88) to reduce the thickness of the movement. The cases were decorated with pearls and enamel (Figure 165).[155] This type of watch was introduced at the end of the Qianlong period, and at first was not standardized.[156] Some of them had a calendar and date display. Perhaps because the dials were too complicated, Qianlong stated in 1782 that such watches were not needed, but only chiming enamel watches.[157] This demand by the largest Chinese buyer of Western watches underlines the importance of the fine enamel painting on the case.

In the 1780s, the Swiss clock and watchmaking firm of Jaquet-Droz provided Cox in Guangzhou with pocket watches.[158] Other Swiss makers soon sought to exploit the market. Functionality in these watches took second place to artistry in the case decoration and ingenuity in the mechanism, which was frequently fitted with repeating work and/or music. The introduction of the **hanging barrel** allowed the back plate to be suppressed so that the highly decorated movement could be seen. Although Swiss watches frequently used a cylinder or standard duplex escapement, a characteristic form of the latter with forked locking teeth became popular for these 'Chinese' watches. A centre seconds hand, which showed at a glance that the watch was active, was obligatory, and since the watch was for show it was worn on a belt.[159] Although these models were expensive, they were welcomed by wealthy Chinese customers particularly because the enamelling of the case was completely different from Chinese painting techniques. Realistic figures or flowers aroused Chinese attention. Musical and striking functions were also always a Chinese preference. Such watches were often sold in pairs, a traditional Chinese concept signifying harmony (Figure 114).[160] Even court display clocks may be in pairs.[161]

Until the early nineteenth century, British traders in Guangzhou were predominant in the market. One such was Charles Magniac (1776–1824) who arrived in Guangzhou in 1801. His father Francis Magniac (1751–1823) was a clockmaker in London. Their company had been selling clocks and watches in China, and even after the 'clock crisis' of the 1810s, their clock business continued, ceasing only in 1824.[162]

From the 1820s, Switzerland increasingly dominated the pocket watch trade with China.[163] In 1818, Edouard Bovet (1797–1849) arrived in Guangzhou. Responding to the current state of the Chinese market, he made several partnerships for manufacturing and selling pocket watches.[164] These models gradually became typical. In Chinese, they had a specific name, the Chinese calibre watch 大八件, and were described as such in a work published in 1832—they were the final version of the Chinese market watch.[165] Characterized by the use of a going barrel and suspended movement, Chinese calibre watches divide into two groups: the luxury version and the simple version. The former has a case usually

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149 Cranmer-Byng 1962, 261, but this is probably an exaggeration.

150 Chen 2014a, 120. About British watch and clockmaking in the eighteenth century, see Stirling-Middleton 2018, 37–41.

151 Chen 2014b, 116–17; Smith 2013, 25; this volume Chapter 16. For technical details about British clocks in the Palace Museum, see Wang & Qi 2017.

152 Ye 2008, 132. J. H. Cox's company is the predecessor of Jardine Matheson & Co. For Cox see White 2012, 94–150 and 158–207 for his clocks. For J. H. Cox, see White 2012, 151–6.

153 White 2019, 340–1. My thanks to Ian White for supplying the birth and death dates.

154 Vaucher 2003. The Ilbery family enjoyed strong commercial and technical cooperation with the Swiss watchmaking world. And James' son, James William Henry Ilbery (1811–96), was an apprentice in Fleurier.

155 Tellier 2010, 17–18. Such watches manufactured by Ilbery entered the Chinese market in the early nineteenth century.

156 Qing 2016, 245.

157 Guo 2013, 135.

158 For some original archival records, see Chapuis 1919, 62–3.

159 A good survey of Swiss watchmakers working for the Chinese market is given by Chapuis 1919.

160 Chapuis 1944, 137. The resulting mirror enamel pair is also a feature of the Chinese market watch, see Didier 2010, 27–9.

161 Chang 2016, 44–5. The most recent survey of Chinese watches is White 2019.

162 Greenberg 1951, 27–8, 86–7.

163 Bonnant 1964, 41–5. By the early nineteenth century, the British paid more attention to the profits brought by the export of cotton and subsequently opium from India, and the watch trade was gradually abandoned.

164 Chang 2016, 24–8. At first Edouard Bovet also came to Guangzhou as an employee of a British watch company.

165 Deng 1832, Vol. 6, 3.

Figure 20 Bovet pocket watch, simple version of the 'Chinese calibre watch' with an enamelled movement, using the shape of a Chinese dragon. D: 60mm. *c.*1860. Private collection. Photo: Tao Yanhe.

made of gold with enamel and pearl decoration, while the latter was usually silver cased without any exterior decoration.[166] Although externally different, the structure of the movement is similar but made in two materials: one of brass with engraved patterns, the other in polished steel. Special movement designs used the Chinese dragon and phoenix shape, sometimes with enamel decoration (Figure 20). Although all this increased the difficulty of manufacturing, they vividly reflect Chinese taste, indicating that the Swiss manufacturers had closely studied Chinese preferences.[167]

With the opening of trade in Shanghai and other cities in 1842, the Guangzhou trade monopoly was destroyed, and brands other than the Chinese calibre watch entered the mainland.[168] Specialized watch stores appeared in Shanghai, and opened branches in different cities. Laidrich & Vrard (later renamed L. Vrard & Co.), founded in 1860, was the most famous. The firm was founded by the Swiss, Edouard Laidrich (?–1869), and the French Ludovic Vrard (1833–1916). The northern branch was independently operated by Pierre Loup (1840–99) from 1881.[169] The sale of Chinese calibre watch continued until the end of the nineteenth century. The reason they achieved such unprecedented success was not only promotion by the sales network, but also, more importantly, the integration of this type of watch into Chinese culture. Firstly, almost all brands used Chinese patterns and characters as trademarks. Secondly, some models used the Chinese twelve 'double hours' method to comply with the Chinese traditional horary system.[170] Of course, there were also visual elements, such as centre seconds, the transparent cuvette, and the engraved movement, all of which were favoured in China and which differed from contemporary European pocket watches.[171] After 1850, the enamel painting on watchcases used more Chinese elements, such as landscapes, flowers, birds, and portraits.[172] This customized concept showed that the Chinese were not passively buying watches, but were actively proposing different models.

The position of Chinese calibre watch in the Chinese market was well summarized by Kiu Tai Yu (1946–2020):[173]

> This looks characteristic of the Chinese calibre pocket watch (Figure 20), the type and shape of the escapement in the movement are various. The materials, layout design, manufacturing process, and craftsmanship of the movement differ. Therefore, each of the Chinese calibre watches has its own characteristics, and no one is exactly the same. . . . Chinese calibre watches have the longest monopoly in the huge Chinese market and have the largest number of Chinese brand names. With its quality, beauty, variety, quantity, and coverage, it has created the biggest miracle in watches![174]

How did pocket watches affect the Chinese? In 1670, the traditional 100 'quarters' system was changed to the ninety-six 'quarters', a phenomenon of the Qing Dynasty using the Western calendar, which essentially accorded with the Western time system.[175] The Emperor Yongzheng (r. 1723–35) inherited the calendar promulgated by his father Kangxi. The Imperial Astronomical Agency used timepieces to check the time when observing astronomical phenomena.[176] In the history of the Qing Dynasty, Yongzheng was known for his diligence and dedication, and the eunuch in charge of pocket watches provided his timekeeping. He asked the imperial workshop to make some cases for pocket watches in 1726, perhaps for the emperor so that he could use the pocket watch at any time to keep track of time.[177] The clocks and watches used by Qianlong not only appeared in the court but were also used while travelling. For example, during the southern tours of 1756 and 1761, twenty small clocks and watches

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[166] Chapuis 1919, 162–3.

[167] Chang 2016, 72–9.

[168] The main brands are Vaucher (富碩), Dimier (點耶), Juvet (有喊), etc., all from Fleurier. For an introduction, see Patrizzi 1980b, 107.

[169] Niklès van Osselt 2013, 81; White 2019, 6–7.

[170] Taking Bovet as an example, it adopted Chinese (播喊) as a trademark in the 1830s. In 1878, Bovet launched a twelve 'double hours' pocket watch, See Chang 2016, 43, 89.

[171] Obviously, the Chinese market watch tends to be more artistic. Chinese buyers tended to appreciate pocket watch design more than the utility of timekeeping. At that time, the Chinese preferred the centre seconds design, so that it could have visual dynamics.

[172] Chapuis 1919, 186–7. For an overview of the development of pocket watch enamel technology, see Fallet 2015, 260–3.

[173] Kiu Tai Yu is a well-known watch collector, watchmaker, and horology historian in China.

[174] Kiu 2006, 63–4.

[175] Zhan 2010, 133. A day is divided into ninety-six quarters, and each 'double hour' is exactly eight quarters, which is equivalent to four quarters in an hour. Through the use of clocks and watches, people in the Qing Dynasty gradually accepted the timekeeping method of Western.

[176] Zhu et al. 1999.

[177] Guo 2013, 112–14.

were required for each. Obviously, these were prepared for timing.[178] Although the frugal Jiaqing publicly stated that he did not like luxury items from the West, he wrote a poem specifically about pocket watches,[179] in which he described their accuracy. Although the emperor's clock had an amusement function, we cannot deny the importance of timing to him, and the importance of the pocket watch.

In the Qianlong period, pocket watch users were not only members of the imperial family, but also were senior officials in the court. To facilitate the scheduling of government affairs, these officials became accustomed to using watches.[180] There is documentation that shows how ministers fixed small watches in their belt buckles to facilitate using them. When Yu Minzhong (1714–80) wrote an official document, he would place his pocket watch next to the inkwell to prevent delay in submitting it. When the clock in Jiaotai Hall was ringing at noon, he instructed his colleagues to wind up the watch. Similarly the attendants of Fu Heng (1722–70) all had pocket watches that they checked with each other.[181] But until the middle of the nineteenth century, pocket watches were generally owned only by officials and the wealthy. It was during the Emperor Guangxu's reign (1875–1908) that increasing numbers of men and women at more popular levels of society began to use pocket watches, with consequent effects on their concept of time, especially for those living in cities.[182] It should be noted, however, that although pocket watches were becoming popular during the Qing Dynasty, no watchmaking industry had yet been established in China. Superficially the large quantity of imported watches would seem to have inhibited the development of domestic watches, but the root cause was the lack of knowledge and the technology for watchmaking in China.

POPULAR CHINESE CLOCKMAKING

In the first half of the seventeenth century, as missionaries preached throughout China, clocks became familiar to increasing numbers of people, and curiosity led to their imitation. The imitators were mainly to be found in Nanjing, Shanghai, and Zhangzhou.[183] The missionary Álvaro Semedo (1585–1658) mentioned in his book that Chinese craftsmen could make table clocks,[184] indicating that the Chinese already used mainsprings by this time. In the second half of the seventeenth century, in addition to the above-mentioned areas, records of clocks in the Guangzhou, Suzhou, and Hangzhou regions also appeared. A Russian mission met with Kangxi in 1676, and a member of the mission noted that Guangzhou artisans had full ability to copy and make large clocks.[185] The most detailed record, however, is of the work of Ji Tanran (*fl.*1655). He had seen Westerners make clocks and imitated one that he called the 'Heavenly Pagoda' (通天塔), using brass gears, and fitting a striking device and automata.[186] It was closer to the Western clocks than Wang Zheng's design. Generally, this was a period of apprenticeship and imitation, as an original craft industry had not yet formed.

The development of the Chinese clock industry came in the eighteenth century. With the increase of family workshops in different regions, local clocks took on their own design characteristics.[187] The scholar Qian Yong (1759–1844) noted that artisans in Guangzhou, Nanjing and Suzhou could all make clocks.[188] Although they were not the only places where clocks were made, by the mid-nineteenth century, Guangzhou and Nanjing were the two major clock-making centres, producing different styles of clocks: the Guang clock (廣鐘) and the Su clock (蘇鐘).

European clocks coming through the Guangzhou trade were mainly supplied to the Emperor through the tribute system or acquired by wealthy merchants The Guang clock developed in this market.[189] In the 1780s, the Guang clock entered a peak period

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[178] Guan 2011, 140.

[179] Interestingly, he was the first emperor to write poems on the theme of pocket watches, indicating that his focus on pocket watches focused on practicality.

[180] In 1816, Clarke Abel (1780–1826), a member of the Amherst Mission, discovered that Chinese officials were curious about pocket watches. He could not determine which aspect aroused this curiosity—as timer or ornament? His doubts were justified because pocket watches were mainly owned by the Imperial family and ministers at that time, and local officials had not generally begun to use them.

[181] Chang & Bai 2009, 87, 111.

[182] Zhan 2010, 127–8. With the advent of the public clock tower, the individual's emphasis on the accuracy of the timer will become more obvious.

[183] Zhou Hui (1546–*c.*1627) documented that Huang Fuchu (*fl.*1611) produced a clock in Nanjing, Chen Xinfu was a craftsman from Zhangzhou, see Li 2012, 44–5. When missionary Lazzaro Cattaneo (1560–1640) was in Shanghai, locals were able to make oversized clocks; see Tang 2017, 457.

[184] Semedo 1655, 27.

[185] Zhu 2018, 46. In 1676, a craftsman named Cham in Suzhou was able to repair clocks for missionaries, see Golvers 1999, 548–9. Huang Luzhuang (1656–?) and Zhang Shuochen (*fl.*1662) in Hangzhou also made clocks; see Li 2012, 47.

[186] Needham 1965, 515. This clock had a Chinese design style, but the quality was relatively low and it could not run for a long time, indicating that the manufacturing of the mainspring was immature. Entering the eighteenth century, Sun Ruli of Zhangzhou was able to manufacture 10cm clocks, and the mainspring technology was relatively mature.

[187] The market and demand will determine the development of an industry. In the Qing Dynasty, the clock was regarded as a status symbol. This consumer psychology affected the style of the local clock industry, without influencing that of Western clocks made for the Chinese market.

[188] Qian 1997, 321. The clock-making technology also interacted between Fujian and Guangzhou. Leng 2012, 51.

[189] Records of Guang clocks already appear in the court archives in 1723. At first, they were only simple imitation of Western clocks,

characterized by three elements: firstly, a resemblance to Chinese architecture or goods; secondly, the use of enamel decoration in blue, green and yellow; thirdly, the provision of many automata and musical devices.[190] In addition to gorgeous and mechanically complex clocks, the Guang clock was also produced in simpler market versions. Production reached a peak of more than 2,000 sales per annum in the 1870s, and local horological guilds also appeared at that time.[191]

Nanjing was the centre of a clockmaking industry, and clockmakers from there took their skills to surrounding cities. The famous Suzhou clock-making centre had a close relationship with Nanjing. The inscriptions recorded in the cemetery of the Suzhou horology guild in 1816 not only indicate that some local clockmakers came from Nanjing, but also that Suzhou clock-making was already of a good size.[192] In 1853, there were two clock-making workshops in Yangzhou. The workshop owners came to Yangzhou from Nanjing in order to avoid the war of the Taiping Heavenly Kingdom.[193] The clock-making methods in these cities were based on family workshops, using manual manufacturing and a division of labour.[194] Compared with Guang clocks, Su clocks were mainly aimed at the mass market, and did not emphasize gorgeous appearance. They can be divided into three categories: striking clocks for the 'night watches', clocks with automatic jacks, and 'screen clocks' (插屏鐘), the main style, popular in the last 25 years of the nineteenth century. Clock cases were usually made of wood, with a round dial mounted on a square, copper plate engraved with various patterns. The movements were mostly spring driven, with a fusee, a crown wheel escapement, and a bob pendulum.

On 4 July 1851, Daniel J. Macgowan (1814–1893), the American missionary in Ningbo, wrote about the scale of the clockmaking industry in Nanjing, Suzhou, Hangzhou, and Ningbo. He believed that the annual output of these four places was about 1,000 pieces, their prices at 7–100 dollars, with an average price of about twenty-five dollars.[195] These data reflected the fact that the Chinese clock industry still relied on manual manufacturing and could not mass produce. Although the appearance and style of Chinese clocks had been formed, they lacked innovation in movement technology.[196] After the Opium War, China's commercial centre moved from Guangzhou to Shanghai, and the clock-making industry also developed there on the basis of available business capital.[197] In 1876, Ningbo native Sun Tingyuan (*fl.* 1906) founded the May War Lee(美華利)company in Shanghai, mainly dealing in watches and clocks from Europe. Later, his son Sun Meitang (1884–1959) introduced mechanized production, which meant that China's clock-making industry entered the era of industrialization.[198]

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and were not recognized by the emperor because of quality problems. Beginning in the 1760s, they gradually absorbed the creativity of British clocks in automata, and in appearance became less dependent on Western elements, a more local Chinese design being used, see Huang 2013, 18–19.

[190] Huang 2013, 25–7. At the end of the eighteenth century and the beginning of the nineteenth century, Guang clocks became cheaper, at only one-third the price of similar British goods; see Cipolla 2003, 109.

[191] Li 2012, 50. There were many simple versions that used a weight-drive, such as wall clocks.

[192] In the late Qing Dynasty, there were more than twenty workshops, with fewer than 100 employees in Nanjing; nearly twenty workshops, with more than fifty employees in Suzhou. The movements, wooden cases, and engraved copper plates were made locally in Nanjing, but some accessories needed to be purchased from other places, such as dials from Guangzhou and bells from Suzhou and Yangzhou. Song 1960, 18–21; Pagani 2001, 79–80.

[193] In the late Qing Dynasty, there were twenty workshops, with nearly 100 employees in Yangzhou. Most of the fusee chains produced in Yangzhou were made by rural women and supplied to Suzhou and Shanghai. Yangzhou was famous for making small Screen Clock whose movement height was within 10cm. Wu 1984, 105–8.

[194] Chen 1981, 90.

[195] Macgowan 1852, 336. This is an article about the Chinese clock market that he wrote for the US Patent Office. He recorded the number of clockmaking workshops: forty in Nanjing, thirty in Suzhou, seventeen in Hangzhou, and seven in Ningbo.

[196] The movement still used the crown wheel escapement, and costs could not be reduced. As a result, Chinese clocks could not compete with German and Japanese imported clocks in the 1890s, and they gradually withdrew from the market.

[197] In the late Qing Dynasty, there were nearly ten workshops, with fewer than forty employees in Shanghai; see Wu 1984, 115.

[198] Sun 1925, 1. May War Lee established a clock factory in Ningbo in 1906, relocated to Shanghai in 1912, and used machine manufacturing in 1915.

SECTION THREE: MODERN CHINA

Ron Good and Jon Ward

At the turn of the twentieth century, domestic Chinese production was limited to what could be produced by skilled craftspeople in small and independent workshops dispersed throughout China. Although these smaller shops used then-current tools, they were still centred around manual production of individual pieces. There were no large-scale manufacturers, nor was there any assembly-line production of clocks or watches. Moreover, these few domestic clock makers had to compete against imports that dominated the Chinese market. By the 1920s, however, assembly-line production was firmly in place, largely spearheaded by the vision of two entrepreneurs, Sun Meitang, founder of the Meihuali Watch and Clock Co. Ltd, with its beginnings in 1905, and Li Dongshan, founder of the Baoshi Clock Factory (or Yantai Baoshi Clock Factory) in 1915. Sun Meitang was the son of the owner of the Meihuali Watch Shop, founded in Shanghai in 1875 as a franchise seller of imported watches and clocks. Convinced that China should and could manufacture clocks to compete with outside manufacturers, Sun Meitang opened the Meihuali Watch and Clock Co., Ltd in Ningbo, Zhejiang Province, just south of Shanghai, in 1905, and moved its operations to China's first modern assembly-line style clock factory in the Yangshupu district of Shanghai, in 1913. By 1915, Meihuali was producing clocks for domestic and foreign markets and even winning awards at a Panama Pacific World Exhibition in San Francisco.[199] The year 1915 also saw the very significant birth of the Yantai Baoshi Clock Factory, later known widely as Yantai Polaris, which is presently China's longest existing watch and clock company. Li Dongshan, the owner of a Yantai hardware retail company, the Shunde Xing Hardware Co. Ltd, had also been inspired by foreign clocks carried in his store. He realized, like Sun Meitang in Shanghai, that this represented an opportunity for new domestic industry. Leaving Yantai in 1913, Li travelled to Germany to learn about clockmaking. He returned in 1915, and after a further six months in Japan, opened his own factory, which produced its first finished clocks in 1918 (Figure 21):

> Most of these 'Nanjing clocks', [so named because the style was born in Nanjing during the Jiaqing period of the Qing Dynasty], have the shape of a square box, and the clock stands are carved from rosewood or mahogany, generally divided into three layers. The chassis is slightly larger with four tiger feet supporting it. The middle layer is a screen inserting frame, with groove inserts on both sides; the upper movement box can be inserted into the middle layer frame imitating the traditional screen inserting process, so it is called the screen inserting clock. The upper movement glass frame is mostly inlaid with mahogany snails. The lower and middle layers are carved and embossed, which is exquisite, antique, and elegant. Even more exciting is the clock face, which has a variety of white porcelain, enamel and bronze carving styles, as well as the copper base plate around the round clock face, decorated with eight immortals and auspicious patterns of opera, etc., to add beauty and interest.[200]

In the years that followed Baoshi's founding, and as its production of wall, alarm, and pendulum clocks became successful and were exported broadly through Southeast Asia,[201] over thirty more clock factories were established in other coastal cities, mostly by Yantai entrepreneurs.[202] The most notable of them today, Tak On Clock Factory in Shanghai, opened in 1932. After suffering extensive damage from bombing in 1937, it was rebuilt the next year and renamed Jin Xing Industrial Association, producing alarm clocks with the *Zuanshi* (Diamond) brand name.[203] In the ensuing years, it became one of China's most prominent horological enterprises. By 1925, the Meihuali Watch and Clock Co. Ltd had 643 employees and twenty-five retail branches in China, but it suffered a different fate. Meihuali's facilities were fully destroyed by the wartime bombing that had only disrupted Tak On, causing it to cease operations altogether.[204] Other, newer, Shanghai companies had better fortunes. The China Clock Factory, for example, introduced a '555' brand fifteen-day clock in 1940. Although production stalled during the Japanese occupation, by the early 1950s '555' clocks were again becoming very popular, and the company also developed highly accurate astronomical clocks.[205]

Domestic watchmaking in China, up to the mid-1950s, was almost exclusively limited to workshops established between 1926 and 1943 (including the most prolific, Huacheng Watch Case Factory) that only cased foreign movements. Domestic movement makers did not exist.[206] That changed when work began in both Shanghai and Tianjin to create the first Chinese-made wristwatches. A small workshop in Tianjin was the first to produce a prototype on 24 March 1955.[207] Named *Wuxing* (Five Stars),

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[199] Zhang, 2016.

[200] Lan 2010.

[201] Li 2015.

[202] China Daily 2015.

[203] Chan 2007c.

[204] Zhang 2016.

[205] Zhang 2014.

[206] OSC 2003.

[207] Jin 2013.

Figure 21 Nanjing Clock.
Photo: David Chang.

Figure 22 Tianjin 51 model wristwatch. Photo: Jon Ward.

Figure 23 Tianjin Sea-Gull ST5 movement. Photo: Ron Good/AMCHPR.

it used a virtually handmade copy of a Sindaco five-jewel pin-lever movement. Shanghai's first prototype, modelled after an A. Schild 1187, was finished in September 1955. Soon, Tianjin and Shanghai were producing watches for retail sale: Tianjin with its '51'-branded models (Figure 22), and Shanghai with the 581 series. Other popular series from both companies soon followed, along with steady improvements in durability (anti-shock modules, for example) and adaptations to facilitate more efficient mass production.

The third of the original major Chinese watch factories, Beijing Watch Factory, was founded on 19 June 1958, producing under 4,000 of its original BS1 model by 1961. That year, Beijing purchased an entire Swiss assembly line and began production of its anti-shock BS2 model, and by 1968 had produced 166,861 BS2 watches.

Other watch factories were also established in 1958, in an additional five cities: Guangzhou, Nanjing, Qingdao, Jilin, and Andong (now Dandong). At the same time, four Shanghai watch-case companies were merged with Huacheng to manufacture cases for the factories in both Shanghai and Tianjin. In 1959, Shanghai's Jin Xing (formerly Tak On Clock Factory) added stopwatch production, initially mostly for the military.[208] These stopwatches later found a wider market and proved so successful that the factory's name was changed to Shanghai Stopwatch Factory seven years later. Also in 1959, wristwatch production began at the renamed Yantai Clock Factory (formerly Yantai Baoshi). They were given the brand name *Beijixing* (Polaris), a name later given to all of the factory's products. Yantai had greatly expanded its range of clocks, including developing China's first marine chronometer in 1957, so watchmaking remained a minor activity. The factory became a state-owned company, Yantai Clock and Watch Factory, in 1962.[209]

Tianjin began work on China's first wrist chronograph project in 1961 using equipment purchased from Switzerland's Venus Watch Company.[210] Shanghai introduced the first Chinese calendar watch in 1962, the A623, which Premier Zhou Enlai famously wore for the rest of his life.[211] Tianjin unveiled the first entirely Chinese-designed and manufactured watch movement in 1966. Branded *Dongfeng* (East Wind), reportedly named by Mao Zedong himself,[212] it sported the ST-5 (Figure 23), a reliable and accurate movement and the first watch movement in China that was not highly derivative of a foreign calibre. Shanghai's SS1 movement, a dramatic redesign of its A-581, was an improvement introduced in the same year. Beijing's home-grown improvement of its Swiss-inspired BS2 movement, the SB-5, followed in 1968.

By this time, Shanghai, Tianjin, and Beijing Watch Factories were the 'Big Three' of the Chinese watch industry and captured most of the domestic market for wristwatches, although factories in other cities survived trading to their immediate regional markets.

China's Ministry of Light Industry opened the Clock and Watch Research Institute in Xi'an in 1967, charged with formulating and revising national horological standards, product quality testing, and vocational training. Its research projects led to technological advances in timepieces used for military and civilian purposes, including the development of an aviation clock, mechanical and tuning fork timing devices for satellites, and a quartz marine astronomical clock.[213] The number of watches manufactured in China increased from 500,000 in 1960 to 3.5 million in 1970.[214] A new central government plan to further expand watch production was initiated in 1969. Major investments were made opening watch factories in almost every province and developing a standardized men's watch movement, ordered to be manufactured by almost every watch factory in China. The movement

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[208] Chan 2007c.

[209] Li 2015.

[210] Adelstein 2014.

[211] Dong & Wang 2009.

[212] Adam 2010.

[213] ZBYJS a,b.

[214] Byrd & Tidrick 1992, 60.

Figure 24 Peacock Brand Tongji movement. Photo: Ron Good/AMCHPR.

(given the name *tongyi jixin*: unified movement, normally abbreviated to *tongji*) allowed factories to be more easily constructed all over the country, while interchangeable parts made repairs easier and cheaper. Most important, it allowed for an increase in production, making watches accessible to a greater number of people.[215] *Tongji* design (Figure 24) drew expertise and resources from the eight leading watch manufacturers, the Clock and Watch Research Institute, and Tianjin University. Blueprints for the new seventeen-jewel manual winding movement were finalized in 1971. Over the next few years almost all Chinese watch factories used it.[216] Visually, the resulting movement resembled the Enicar 1010, to a degree that suggests at least some influence, but with a seventeen-jewel count compared to the Enicar's usual 21.

The first mass-produced *tongji* watches were released to the public in 1972 by Shanghai No. 2 Watch Factory with the brand name *Baoshihua* (Gemstone Flower).[217] Beijing produced its first *tongji* the same year. Other factories soon followed. Even though movement design was standardized, some factories developed their own variations containing parts compatible with other factories' movements, adding higher jewel counts or simple complications. The Shanghai Watch Factory marketed its first *tongji* watches in 1974. These nineteen-jewel variants were of particularly good quality, and quickly became the most desired domestically manufactured watches in China.[218] The English language text which appears on some of them suggests that they were intended for export as well as domestic use, although Chinese watches were still exported in only very small numbers at this time.[219] The *tongji* was a remarkable domestic success. Within a decade, thirty-eight enterprises were manufacturing complete watches—more than in any other country at the time.[220] Some of them also delivered movements to one or more of the dozens of additional factories which just cased them.

The Tianjin Watch Factory had been exempted, along with two other companies, Shanghai Stopwatch and Nanjing, from the mandatory switch to the *tongji*. Consequently, Tianjin continued to manufacture its ST-5 *Dongfeng*, which became China's first export watch the year after receiving official approval in 1973. The export version was given a new brand name: the now well-known Tianjin Sea-Gull.[221] Many millions of people were served as production by state-owned factories increased year after year into the 1980s. In addition, the opening of the market after the end of the Cultural Revolution had a formidable effect on exports. By 1981, China had become the world's fifth-largest producer of watches and exported about ten per cent of the overall 28.7 million it produced that year. China also manufactured 27.7 million clocks in 1981, exporting thirty-five per cent of them. Shanghai's factories, amalgamated under the umbrella corporation Shanghai Clock and Watch Company, dominated the domestic industry, producing one-third of the country's watches.[222]

While quartz timepieces were becoming dominant in much of the rest of the world, China's industry was still overwhelmingly based on mechanical movements. This was due to domestic consumer demand; quartz was more difficult to have repaired, and components were harder to obtain. Digital watches were widely shunned by a population that regarded a wristwatch as a treasured possession. While a few factories did manufacture complete quartz timepieces, they could not be produced as economically as their domestic mechanical and foreign quartz counterparts.[223] Demand for some clocks remained high, for example the 555 desk clock,[224] but by this time China's clock market had generally become saturated, and overall domestic production dramatically decreased. In an effort to avoid the same fate for the watch industry, production limits were placed on the factories. No such limits were placed on clock production, which was controlled at the provincial level. However, these limits were not strictly enforced. In addition, some unauthorized factories were founded in a number of smaller cities.[225] But it did not take long for market conditions and consumer tastes to undergo dramatic transformations.

As China's economy opened under the leadership of Deng Xiaoping, a number of Special Economic Zones were established in the southern provinces of Guangdong and Fujian, spurring the formation of new watch companies with joint Chinese and foreign ownership. Lacking the experience of the established

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[215] Teng 2015.
[216] Chan 2008b.
[217] Chan 2008b.
[218] Teng 2015.
[219] Byrd & Tidrick 1992, 60.
[220] Byrd & Tidrick 1992, 63
[221] Adam 2010.
[222] Byrd & Tidrick 1992, 59–60.
[223] Byrd & Tidrick 1992, 63–4.
[224] Yang 2007.
[225] Byrd & Tidrick 1992, 60–1.

Figure 25 Yantai Polaris 100th Anniversary Clock 2015. Photo: Ron Good/AMCHPR.

Figure 26 Modern Chinese Jintuofei Brand tourbillon. Photo: Ron Good/AMCHPR.

factories, they installed inexpensively made foreign quartz movements, mostly from Japan and British Hong Kong, in locally manufactured cases. Soon a huge number of inexpensive, thinner, more accurate watches would flood the domestic market.[226] The Shanghai Clock and Watch Company quickly worked to combat the threat these new competitors posed. A new mechanical movement, designated SBS, was developed to power thinner watches which were coming into fashion. It was a joint project by Shanghai and Shanghai No. 4 (formerly Shanghai Stopwatch) Watch Factories.[227] Within a few years it was the movement used in both factories' flagship wrist watches. A few other factories, including Beijing and Nanjing, designed new, less bulky movements of their own, but despite these efforts, the thinner manual winding movements ultimately failed to achieve the factories' goals.

There was nevertheless a place for mechanical watches in some markets, as long as they were automatic and inexpensive. Guangzhou Watch Factory, hit particularly hard by its nearby southern China competitors, developed an automatic version of its ladies' watch movement. Similarly, Tianjin used its women's ST-6 as a base movement for men's and women's automatic watches. Both factories sold these inexpensive-to-produce movements to be cased by other enterprises in China and Hong Kong. Meanwhile the new enterprises in Guangdong thrived. By 1987 more watches were manufactured in Guangdong than in Shanghai, which had dominated the industry for decades.

The turn of the century saw a new 'Big Three' emerge in China's fashion watch market: Rossini in Zhuhai, and Fiyta and EverBright (now Ebohr), both in Shenzhen. They primarily specialized in the production of quartz watches to meet the demand of a domestic population with ever-increasing incomes.[228] The year 1997 saw the beginning of an official government policy to privatize almost all state-owned enterprises.[229] Within the next few years, a massive reorganization of the Chinese watch industry occurred. Most of the *tongji*-era factories closed, and their assets were sold to private investors. The number of mechanical watch movements manufactured in China plummeted.[230] However, also in 1997, Tianjin Sea-Gull introduced a new (ST16) movement, based on Miyota's workhorse 8200 series.[231] The mechanical watch renaissance occurring outside of China became a welcome opportunity for renewed growth. Several other factories, including Guangzhou and Beijing, also developed their own Miyota-inspired movements. Some of the surviving original Chinese watch factories continued to make complete watches, but a large part of their activities consisted of the manufacture of reliable movements to be used in watches cased elsewhere—a complete reversal of the industry's business model in the first half of the twentieth century.

Sea-Gull's resurrection of its 1960s mechanical PLAAF (Chinese air force) chronograph in 2003 was immediately successful. Beijing released its first tourbillon watches in 2004. In the years following, Sea-Gull, Shanghai, Hangzhou, and, more recently, Guangzhou and Dandong's Peacock Watch released their own tourbillons.[232] A shortage of ETA-style movements in the early 2,000s presented a further opportunity for Chinese movement manufacturers. Sea-Gull and Hangzhou, in particular, took advantage of this, producing their own alternatives. Other companies, like Shandong's Liaocheng Zhongtai Watch Co., Ltd found a profitable niche producing a wide range of inexpensive but decorative watch movements for its own watches as well as for major southern Chinese manufacturers. Dial-side open heart movements are a common example, found world-wide. By 2007, Sea-Gull alone manufactured a quarter of the world's mechanical watch movements, more than any other single company at the time.[233]

More than two decades after the industry's 1997 upheaval, the descendants of six of the eight 1958 watch factories remained in operation. A century after its first assembly-line clock factory was founded (Figure 25), China manufactured nearly ninety per cent of the world's clocks, exporting about eighty per cent of them; 540 million clocks were produced in 2014.[234] In 2009, China accounted for seventy per cent of the world's watch output (although this was only ten per cent of world market value[235]), Sea-Gull and other Chinese companies continue to innovate, producing (besides classic three-handers) quarter and minute repeaters, alarm movements, micro-rotor automatics, tourbillons of varied complexity (Figure 26), and perpetual calendar watches.

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[226] Dong & Wang 2009.

[227] Chan 2007c.

[228] Teng 2015.

[229] Chen et al. 2018.

[230] Teng 2015.

[231] Jin 2013.

[232] Adam 2010.

[233] Adam 2010.

[234] China Daily 2015.

[235] Dong & Wang 2009.

SECTION FOUR: JAPAN

Katsuhiro Sasaki

THE ANCIENT *KEIHYO* SUN-DIAL AND TRAVEL SUNDIAL

One of the earliest mentions of **sundials**, *guibiao* (圭表), in East Asia, appears in the official history books, *Former Han Book,* compiled in 206–8 BCE. Sundials were called *guibiau*(圭表) in ancient China and Korea.[236] The word *guibiau* is made by combining the characters *gui* (圭), a time-scale placed on the ground to measure the length of the shadow, and *biao* (表), a gnomon to make the shadow of the Sun.[237] There is also the word *tugui* (土圭), from the characters *tu* and *gui* (圭) pronounced '*tokei*'. Here *biao* (表) is a gnomon that stands on the ground to cast a shadow from the sun, and *gui* (圭) is the scale that is placed (or drawn) on the ground to measure the length of that shadow (*biao*).[236] The Chinese character *guibiao* made by combining the two characters *gui* and *biao* is the word which means sundial in China, Korea,[237] and Japan. A Chinese character *tugui*, having the same meaning as *gui*, is pronounced as '*tokei*'. Thus, the Japanese word '*tokei*' for clocks originated from the word for sundials.

The first Japanese sundial, a *keihyo* (圭表), was a *guibiao* imported from China. *Keihyo*s were brought with Buddhism and many artefacts by Japanese missions, the *kenzuishi* (遣隋使) and the *kentoshi* (遣唐使), who were sent to China during the Sui Dynasty (581–618) and the Tang Dynasty (618–907), during the Asuka period (538–710) of Japan. Throughout the Nara period (710–94) and Heian period (794–1192), *keihyo*s were used in the bureau of divination, the *Onmyoryo* (陰陽寮), which performed astronomical observations and compiled calendars. When Harumi Shibukawa (1639–1715) compiled and completed the *Jokyoreki* (貞享暦) calendar in 1684, a *keihyo* was one of his main observation instruments.

Many portable sundials are found during the Edo period (1600–1868). Many of them have a bowl-shaped depression 2–3cms in diameter, which carries the hour lines and a gnomon, and they are fitted with a compass. They divide the period between sunrise and sunset into six parts, an **unequal hour** system used throughout the Edo period. Some portable sundials were designed as *netsuke* (根付け) for *inro* clocks. In addition, portable sundials with accessories such as a compass, writing brush, brush and ink case, ear pick, knife, tweezers, and abacus were also made (Figure 27). Japanese people in the Edo period are noted as being among the world's leading travel lovers. The post towns on each highway were always crowded with visitors, such as *daimyos* en route for the capital, Edo, people visiting the Ise Shrine or the eighty-eight temples in Shikoku, and many others. Portable sundials were a necessity for travellers, and paper sundials were also prepared.[238]

THE EMPEROR TENJI'S WATER CLOCK: *ROKOKU*

The *rokoku* (漏刻) is an **inflow water clock** time being shown by the rising water level in the receiving tank. The precision of water clocks, insufficient in early days, was greatly improved during the Tang Dynasty by inserting multiple tanks to equalize the flow rate between the upper tank and the lower one. In particular, the Tang bureaucrat Ryosai (呂才, 606–65), who excelled in astronomy, the calendar, medicine, and music, is known for making the five water-tank type *rokoku*.[239] The *rokoku* is mentioned in the *Nihon-shoki* (日本書紀), which was compiled in the Nara period and recounts the history of ancient Japan. In part 27, in the article on the Emperor Tenji (天智天皇, 626–72) is the statement:

> On the 'April *Kanoto* (辛) *U* (卯)' in summer, the Emperor installed the *rokoku* in a new building and told the time with a bell and a drum for the first time. This *rokoku* was made by himself when he was Emperor Prince. [author's translation]

This suggests that Emperor Tenji started the work of time-keeping and time-telling in 671. 'April *Kanoto U*', 25 April in the lunisolar calendar, corresponds to 10 June in the Gregorian calendar. It is commemorated by the 'Time Day', *Tokino-kinenbi* (時の記念日), in Japan, inaugurated on 10 June 1920 at the Tokyo Educational Museum (now the National Museum of Nature and Science, Tokyo), where a centenary 'Anniversary of Time' exhibition was held in June 2020.

The *Nihon-shoki* also mentions the Emperor Prince's *rokoku* in the article (part 26), on the Emperor Saimei (594–661). 'And Emperor Prince made the first *rokoku* and told the time to the people'. This statement is confirmed by one for 671 stating that the Emperor Prince, Naka-no-Oe-no Oji (中大兄皇子), had already made a *rokoku* eleven years earlier. In December 1981, the Nara National Cultural Properties Research Institution carried out archaeological excavations at Asuka in Nara. It was concluded that lacquer pieces discovered in the excavations must be parts of the *rokoku* made by Naka-no-Oe-no Oji, and of great significance, and it became a big topic.[240]

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[236] For sundials and water clocks in Korea, not otherwise treated in this volume, see Jeon 1974, 42–71; Needham, Gwei-Djien, Combridge, & Major 1986; Hovey 1986.

[237] Needham 1959, 285, fig. 110.

[238] Tsunoyama 1984, 63–4; Chuko-Shinsho 715.

[239] Needham 1959, 324, caption to figure.

[240] Asuka 1983,

Figure 27 A portable sundial with seven accessories. Takabayashi collection, NMNS Tokyo.

Emperor Tenji's *rokoku* has not survived, so it is impossible to know exactly what it was like. However, it is illustrated in the *Rokoku-setsu* (漏刻説) by Yosen Sakurai (桜井養仙) of Chikugo, Yanagawa, in 1732 (Figure 28). This shows it to have consisted of four water tanks, named from the top *yatenchi* (夜天池), *nittenchi* (日天池), *heiko* (平壺), and *suikai* (水海). A dragon-shaped outlet was attached to the bottom of each tank from the first to the third. The fourth tank had a float with a time-scaled arrow, *sen* (箭), the rising level of water against this indicating the time. *Engishiki* (延喜式), a book compiled in the Heian period (794–1185), describes in detail the enforcement regulations for the *Ritsuryo* legal system, and their basis. In the article on the *Onmyoryo* (the divination bureau) the *Engishiki* gives additional details for using the *rokoku*: to indicate the time of sunrise and sunset, the opening time of the main gate of the Palace, the opening and closing times of other gates, and the leaving time for officials.[241] The times given in the description show that time was expressed in the capital by *toki* (辰刻) and *koku* (刻). Twelve *toki*s made up one day and four *koku*s made up a *toki*.

One of the most famous works of classical literature in the Heian period was the *Makurano-soushi* (枕草子) by Sei-shonagon (清少納言), a court lady serving the Empress Teishi (中宮定子), consort of the Emperor Ichijo (一条天皇, 980–1011). A poetess, she was a leading writer of *tanka* based on close observation of daily life and the nature of the four seasons in a delicate feminine way. Time is treated in section 250 of her essay:[242]

> It is very interesting how the time officer performs his work. On a very cold night, I hear the sound of dragging wooden shoes like '*ko ho, ko ho*', the sound of flicking the string of the amulet bow, the elegant voice with which the time officer says his name and tell the time like '*ushi mitsu* (three *koku* of bull *toki*, 2:00 AM)' or '*ne yotsu* (four *koku* of rat *toki*, 0:30 AM)', etc., and also the sound of inserting a wooden plate with the time name to the stand. All of them are very interesting. [author's translation]

The Department of State, *Dajokan* (太政官), the highest organ of the judiciary, administration, and legislation under the *Ritsuryo* system, which Sei-shonagon recorded, was on the east side of the council hall, *Daigokuden* (大極殿), in the centre of the Imperial Palace, while the *Onmyoryo* was on the north side of the *Dajokan*.[243] Seishonagon, who served near the *Onmyoryo*, wrote vividly about various sounds such as the dragging of shoes and even the insertion of the time plate.

FIRE CLOCK: *JIKOBAN* OF NIGATSUDO HALL AND THE GEISHA'S INCENSE-STICK CLOCK

A fire clock utilizes the constant burning speed of candles or incenses. Particularly important, was the *jokoban* (常香盤) (Figure 29) commonly used in Buddhist temples to keep the sacred fire burning and to purify uncleanliness. This was used in the following way.

A trail, 'powder line', for the incense is drawn in a levelled bed of ashes. The incense is lit and its burnt positions mark dawn, dusk,

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[241] Engishiki 1929, i 587–602, O-okayama Shoten, keyword: 延喜式.

[242] Kaneko & Tachibana 1955, 250th step, 675, 'Meiji Shoin'.

[243] Saito 1995, Figure IX–2.

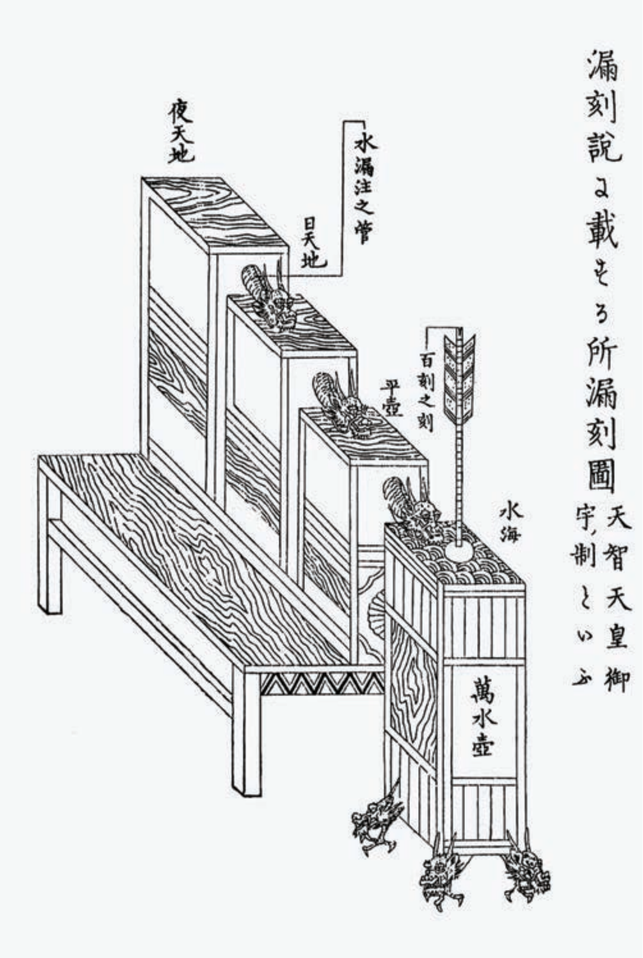

Figure 28 Emperor Tenchi's *Rokoku* from the book *Rokoku-setsu*.

and the following dawn. This determines the burned length of the incense powder line during the day and night, respectively. Using the measured burning length, the dawn-to-dusk or dusk-to-dawn positions on the incense line are marked, each length divided into six equal parts. A bamboo or copper time tag is attached to each position. By reading the burnt position of the incense line with the tag, one can know the hour. *Jokobans* were so simple and easy to use that they were widely used in not only in Buddhist temples but also the houses of the leading local farmers.

It is known, for example, that a *jokoban* has been used at the Water-Drawing Festival, *Omizutori* (お水取り), held in the Nigetsudo Hall of Todaiji Temple in Nara every year, where the *jokoban* was called '*jikoban* (時香盤)'. This festival, in which monks pray for peace, and the order of society, while dedicating sacred water to the 11-faced Kannon in Nigatsudo Hall, has been held for over 1,200 years. It comes to a climax with a powerful fire display using large torches, on 12 March. The *jikoban* is still used for time management at the festival, and is therefore a valuable cultural link between the Nara period (710–794) and the present day, together with various tools, customs, and words related to the *Omizutori*.

Another example of fire clocks is the unique incense-stick clock, *snkodokei* (線香時計), used in geisha houses. The incense-stick clock exhibited in the National Museum of Nature and Science in Tokyo consists of a stand and an abacus (Figure 30). The stand has thin cylinders to hold incense-sticks, and small sprigs or posts on which wooden tags can be hung—the tags bearing the geisha's name.

Using modern time notation, the use of the incense-stick clock is as follows: assume the geisha's working hours are from 6pm to midnight, and that each incense stick burns for approximately 30 minutes. Each geisha has twelve incense sticks. She sells the incense sticks one by one according to the customer's requests, and when they are sold out, her time is finished. This method can be expected to prevent troubles such as double booking, the *senkodokei* can be said to be a very useful work planner for a geisha.[244] As we know that Japanese clocks often appeared in ukiyoes (woodblock prints) painted by artists such as Harunobu Suzuki (鈴木春信, 1725–70) and Utamaro Kitagawa (北川歌麿, 1753–1806), a geisha house was a place where people had a strong interest in time. Unlike artisans, who were paid on completion of their work regardless of how long it had taken, geishas were paid for their time almost literally converted into money.

THE ENCOUNTER WITH EUROPEAN MECHANICAL CLOCKS: FROM XAVIER TO IEYASU

The oldest-known record of the importation of a mechanical clock to Japan is that of the clock given to Yoshitaka Ouchi (大内義隆, 1507–51), the war lord of Suo (current Yamaguchi prefecture), by a missionary of the Society of Jesus, Francis Xavier (1506–52), in 1551. A description which seems to refer to it is found in the geographical work, *Ouchi-Yoshitaka-ki* (大内義隆記).[245]

> Many ships come from Tang, India, and Korea. One of the gifts from India, in particular, which controls the length of the twelve hours equally and makes the bell sound, performs the pentatonic and twelve scales without the playing of a 13-stringed harp by a person. [author's translation]

From this, the gift presented by Xavier can be understood as a musical clock. On the other hand, another description that may refer to the same clock is given by Jean Classet (1681–92).[246] However, he describes the clock given by Xavier as 'a small striking clock', which does not match with the clock described in the *Ouchi-Yoshitaka-ki*. Unfortunately, Yoshitaka's clock was burnt along with the palace during a revolt by his vassal, Takahusa Sue (陶隆房, 1521–55), so its type can no longer be confirmed.

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[244] Sasaki 1996; Bedini 1994a, 181–4.

[245] Hanawa 1793–1819 Hoki-ichi Hanawa, 'O-uchi Yoshitaka-ki', *Gunsho Ruiju*, vol. 394, Kassen-no-bu, ch. 26. *Cf.* the translation, discussion and account of this period in Hiraoka 2020.

[246] Classet 1880 i, 176–7.