4

The Back Dial and Back Plate Inscriptions

DOI 10.1484/J.ALMAGEST.5.110735

M. Anastasiou
Department of Physics, Aristotle University of Thessaloniki, Greece
E-mail: anastasiou@astro.auth.gr

Y. Bitsakis
Department of Primary Education, National and Kapodistrian University of Athens/ Institute of Historical Research/National Hellenic Research Foundation, Greece
E-mail: bitsakis@gmail.com

A. Jones
Institute for the Study of the Ancient World, New York, USA
E-mail: alexander.jones@nyu.edu

J. M. Steele
Department of Egyptology and Assyriology, Brown University, USA
E-mail: john_steele@brown.edu

M. Zafeiropoulou
National Archaeological Museum of Athens, Greece
E-mail: pmitrop@geol.uoa.gr

Abstract

The rear face of the Mechanism consisted of a rectangular "Back Plate" dominated by two large spiral dials. The upper five-turn Metonic Dial represented a 235-lunar-month calendrical cycle while the lower four-turn Saros Dial represented a 223-lunar-month eclipse prediction cycle. A subsidiary quadrant "Games" dial was situated inside the Metonic Dial, and a subsidiary three-sector Exeligmos Dial inside the Saros Dial. Preserved text inscribed around the dials (from the lower right quarter of the plate), probably representing about a quarter of the original inscription, provided further information associated with the predictions of eclipses. This paper describes the reconstruction from the Mechanism's fragments of the surviving parts of the text on the plate and its dials, giving transcriptions and translations. The Metonic Dial inscriptions imply a calendrical scheme similar to that described by Geminos. It was intended to be a version of the calendar of Corinth as it was practiced either at Corinth itself or in some locality of Epirus. The Games dial shows six competitions, four Panhellenic (Olympics, Pythian, Isthmian, and Nemean) plus Naa (Dodona) and very probably Halieia (Rhodes). On the Saros dial there were probably originally about 50 or 51 month cells with a lunar and/or solar eclipse prediction, each carrying a "glyph" and an index letter. Predicted

eclipse times (in equinoctial hours) on the glyphs were calculated as times of true syzygy according to solar and lunar models that both involved anomaly, with the simple Exeligmos dial extending the predictions over three or more Saros cycles. We are reluctant to base a firm construction date on interpretation of the eclipse cycles. The additional information referred to by index letters from the Saros dial was grouped into paragraphs; that for lunar eclipse prediction probably ran down one side of the plate, and that for solar eclipse prediction down the other. Statements about direction may imply a meteorological aspect by referring to predictions of winds attending the eclipses. Five references to colour and size at eclipse are the only Greco-Roman source known to us that suggests prediction of eclipse colors, and might conceivably be linked with astrology.

4.1 Introduction

The rear face of the Mechanism consisted of the so-called Back Plate, a rectangular plate, approximately 316 mm tall by 171 mm wide, dominated by two large spiral dials (Fig. 4.1).[1] The upper Metonic Dial represented a 235-lunar-month calendrical cycle while the lower Saros Dial represented a 223-lunar-month eclipse cycle.[2] Each spiral was defined by a slot cut through the back plate, approximating an Archimedean spiral by means of alternating semicircular arcs, and winding clockwise from the inner to the outer end of the slot, making five complete turns for the Metonic Dial and four complete turns for the Saros Dial. Although there is some uncertainty, it appears that the two outer ends either coincided —so that there was a single continuous slot for both spirals— or came close to doing so.[3] The inner end of each spiral was about halfway between the spiral's geometrical center and the center point of the Back Plate. The scales of the dials ran continuously along the outside of the slot, taking up the entire winding strip of metal between the successive turns and finally running once around the outermost turn. Where the scales came closest to the edges of the Back Plate, they left only small margins. There would have been some overlap of the scale areas of the two spirals near the centre.

Two series of inscriptions belong to the Metonic Dial. (i) The scale of the dial was divided by radial lines into 235 cells subtending approximately equal arcs, representing single synodic months. Every cell contained an inscription, consisting of either just a month name or an ordinal year number followed by a month name. (ii) Immediately inside the innermost turn of the slot, numerals were inscribed at intervals of two or occasionally three cells. When the Mechanism was set to display the chronological and astronomical situation for

1 Freeth, Jones, Steele, and Bitsakis 2008, building on earlier contributions, in particular Price 1959 and 1974, Wright 2004 and 2005, and Freeth et al. 2006. For the estimated dimensions see IAM 1.5.

2 The names used here for the parts of the Mechanism are modern, and reflect modern nomenclature for elements of ancient astronomy. "Metonic" is the modern designation of a period comprising 235 synodic months and (approximately) 19 solar years, as well as of calendrical cycles based on this period. Greek writers attributed it to Meton of Athens (fl. 432 B.C.) though it was known earlier in Mesopotamia and served as the basis of regulation of the Babylonian calendar from about 500 B.C. on (Britton 2007). In Greek texts it is called ἐννεακαιδεκαετηρίς ("19-year period") or ἐνιαυτὸς Μέτωνος ("year of Meton"). "Saros" is the modern name for a 223 synodic month eclipse period also known to the Babylonians (who called it, with convenient inexactitude, "18 years") and the Greeks (who called it περιοδικός, "periodic," according to Ptolemy, *Almagest* 4.2). Greek sources use the name Σάρος for different chronological intervals of allegedly Babylonian origin, and it was Halley who mistakenly associated it with the 223 synodic month period; see Neugebauer 1957, 141-142.

3 IAM 1.5.

a particular date, the cell indicated by the pointer-follower of the Metonic Dial gave the current year and month in the calendar cycle.[4] If this cell lined up radially with a numeral inscribed along the inner rim of the slot, this meant that the month had twenty-nine days instead of the "normal" thirty, with the day number corresponding to the numeral skipped over in the count of days.

The Games Dial was a small subsidiary dial situated in the right half of the space at the center of the Metonic Dial;[5] its circle was divided by two engraved diameters into four approximately equal quadrants. It too has two series of inscriptions (iii): inside each quadrant is an ordinal year number, while outside the perimeter of each quadrant are names of athletic competitions. The pointer of this dial would have shown the position of the current calendar year in a repeating four-year cycle, as well as competitions taking place in that year. (A second subsidiary dial, the Callippic Dial, is conjectured to have occupied the left half of the central space.)[6]

The Saros Dial's scale was divided by radial lines into 223 cells subtending approximately equal arcs, again representing synodic months. Only one series of inscriptions accompanied this dial: (iv) in some of the cells of the scale, highly abbreviated texts (named "glyphs" in recent scholarship)[7] indicated the possibility that a lunar or solar eclipse might occur in the corresponding months, as well as a time of day or night for the eclipse. About one-quarter of the cells had such a glyph, while the remainder were left vacant. The subsidiary Exeligmos Dial, situated in the right half of the space at the center of the Saros Dial, was divided radially into three approximately equal sectors (v): two of the sectors contain numerals, while the third seems to have been left vacant. When this dial's pointer indicated one of the numerals, that number of hours was to be added to the times given in the glyphs.

The space left around the two spirals consisted of four roughly triangular spaces at the corners and two larger, again roughly triangular, spaces halfway down the two sides of the plate. The only remains of the plate outside the dials, preserved in Fragments A, E, and F,

4 For the structure of the pointer-followers of the spiral dials see Anastasiou, Seiradakis, Carman, and Efstathiou 2014, 3-7, and IAM 5.5, commentary to lines II 5-15.

5 It should be noted that Price 1974, 44 conjectured that the main upper dial (which is in fact the Metonic Dial) might be a four-year dial.

6 Wright 2005, 11 conjectured that the extant subsidiary dial (the Games Dial) inside the Metonic Dial was a Callippic Dial. A preserved passage of the Back Cover Inscription (II 17-19) referring to the Metonic and Callippic periods makes the former existence of a Callippic Dial probable, and in Freeth, Jones, Steele, and Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 23 it was hypothesized to have occupied a position to the left of the Metonic Dial's center.

7 The term was introduced in Freeth et al. 2006, 589 and Supplementary Information 5

come from its lower right quarter, wrapping around the right half of the eclipse spiral, and accounting for about half of the larger triangular area in the right center and most of the smaller area in the lower right. In all three fragments, the plate outside the Saros Dial is inscribed with parts of a single text (vi), the "Back Plate Inscription". It seems likely that other parts of this inscription occupied all six triangular spaces outside the dials; if so, we have about a quarter of the original text. This text provided further information in connection with the predictions of eclipses on the Saros Dial.

This paper contains new, critical editions and translations of all the inscriptions on the Mechanism's rear face. For the inscriptions of the upper dials (the Metonic and Games Dials) we have not seen a need to provide extensive commentaries, but we summarize the principal findings of the 2008 paper and draw attention to a few developments in our understanding of these inscriptions since 2008.[8] We offer a more extensive treatment of the Saros Dial and Back Plate Inscriptions, based on findings that we obtained between 2007 and 2012 in the process of preparing our editions. Two recently published papers report and develop some of these findings (which were communicated to their authors);[9] however, we believe it will be useful to present our analyses and arguments more or less as they stood in 2012, making the necessary adjustments to take into account more recent revisions in the texts of the inscriptions, and referring to the more recent publications for a few salient additions or corrections.

8 Anastasiou, Seiradakis, Carman, and Efstathiou 2014; Iversen 2011, 2013a, 2013b, and 2015. Paul Iversen's work on the Metonic and Games Dials (in part in collaboration with John D. Morgan) will be reported in greater depth in Iversen (forthcoming, a) and Iversen (forthcoming, b).

9 Carman & Evans 2014 (see in particular pp. 697 note 2 and 765); Freeth 2014 (see below, note 34).

4.2 Location and layout of the Back Dial and Back Plate Inscriptions

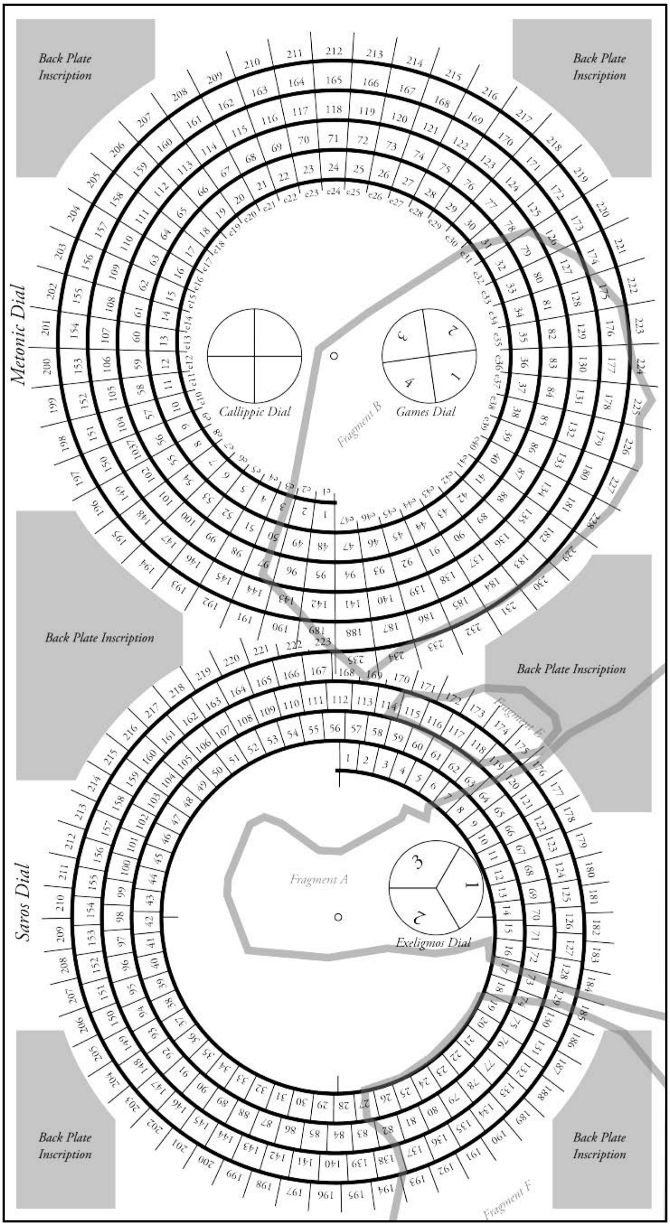

Figure 4.1: *Reconstruction of the back face of the Mechanism, with scale cells and sectors numbered for reference. Regions of the plate surviving in the major fragments are approximately indicated by dark gray outlines*

The surviving parts of the Mechanism's back face are divided among four of the major fragments, which were originally contiguous but had broken apart by 1902 when Fragments A and B were discovered in the Museum.[10] Fragment B preserves part of the upper half of the back face, while parts of the lower half are present in Fragments A, E, and F. In addition, we have two small fragments (24 and 25) of accretion material that formerly adhered to the lower back face, preserving mirror-reversed imprints.

Fragment B (see supplementary Fig. S2), the second largest fragment of the Mechanism, has dimensions 111 mm (height), 98 mm (width), 20 mm (thickness). B-1 preserves about a third of the spiral scales of the Metonic Dial and about a third of the space inside the spiral, including the entire Games Dial. On B-2 are the remains of a bridge radially crossing the turns of the spiral, which was there to provide them with support and stability, and a single gear that directly drove the pointer of the Games Dial. A layer of accretion material bearing the mirror-reversed impressions of the Back Cover Inscription overlays about three-quarters of B-1; a small bit of the Back Cover plate itself is also present. A substantial portion of the pointer of the spiral is lodged in the space between the accretion layer and the Back Plate.

Part of the Metonic Dial scales that is not behind the accretion layer is now exposed but has undergone much surface damage. In photographs from 1902-1918, this region was wholly concealed behind a layer of patina. This material was probably removed during the conservation work of 1953. In addition to providing the only means of reading the dial inscriptions in Fragment B that are not now exposed, CT has also proved more effective than PTMs for the exposed area (Fig. 4.2).

10 The original configuration of Fragments A and B was deduced by Price in 1958 (Price 1959, 62-64) and, as he later reports, confirmed in 1961, apparently by fitting the fragments together physically (Price 1974, 47). Bromley and Wright established the correct placement of Fragment E around 1990, and Wright has published a photograph taken at that time showing A, B, and E fitted together in their approximate relative positions (Wright 2004, 9, Fig. 10, and Wright 2005, 10, Fig. 5). Fragment F's location immediately below Fragment A was established by Freeth et al. 2006, 589, Fig. 4. Conservation carried out around 1905 and 1953 removed material from the surfaces of fragments A and B, so that little if any of the original contact surfaces survive.

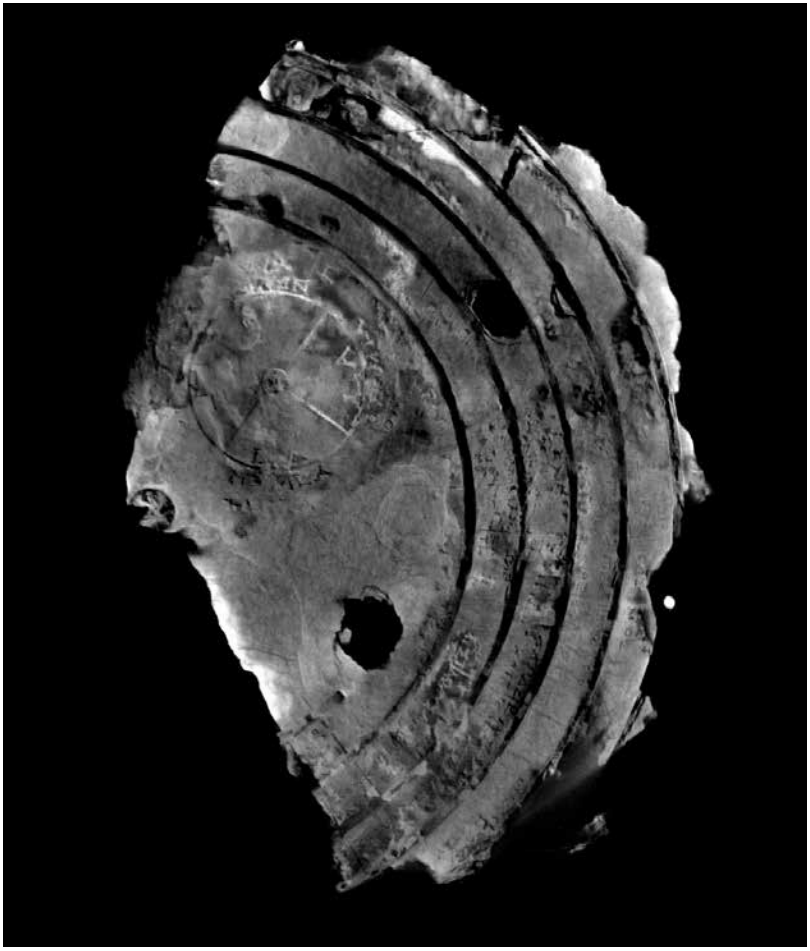

Figure 4.2 : *Fragment B, CT composite image*
(Image: Antikythera Mechanism Research Project)

Fragment A (supplementary Fig. S1), the largest surviving piece of the Mechanism, has dimensions 174 mm (height), 164 mm (width), 55 mm (thickness). It preserves a major portion of the gearwork that led by various complex trains from the rotary input on one of the Mechanism's sides to those outputs on the front and back faces relating to solar and lunar motion, chronological systems, and eclipse prediction. A-2 also retains part of the lower half of the Back Plate itself, including parts of the Saros Dial and the entire Exeligmos Dial. Overlaying part of the Back Plate is an accretion layer of corrosion products bearing mirror-reflected offsets of the Back Cover Inscription. This layer conceals parts of the dials. The entire inscribed area of the Back Plate outside the Saros Dial is exposed, though parts are obscured or obliterated by surface damage. We have depended primarily on PTMs and photographs for the exposed inscriptions on Fragment A, and on CT for the inscriptions concealed behind the accretion layer.

Fragment E (Fig. 4.3), 37 mm height, 61 mm width, 14 mm thickness) consists of three layers of material. The lowest layer comprises part of the Saros Dial and the surrounding area of the Back Plate. Next, and entirely covering this, is part of the layer of accreted material bearing the offsets of the Back Cover Inscription. Topmost, though partly broken away so as to expose the offsets on the accretion layer, is part of the Back Cover itself. Fragment E was originally attached to the rear face of Fragment A, but had already become separated when the Mechanism was discovered in 1902. It lay unrecognized in the Museum's store until 1976, when it was found by the museum's curator of bronzes, Petros Kalligas, who sent photographs of it to Price on April 4.[11] The inscriptions on the Back Plate in E can only be seen in CT.

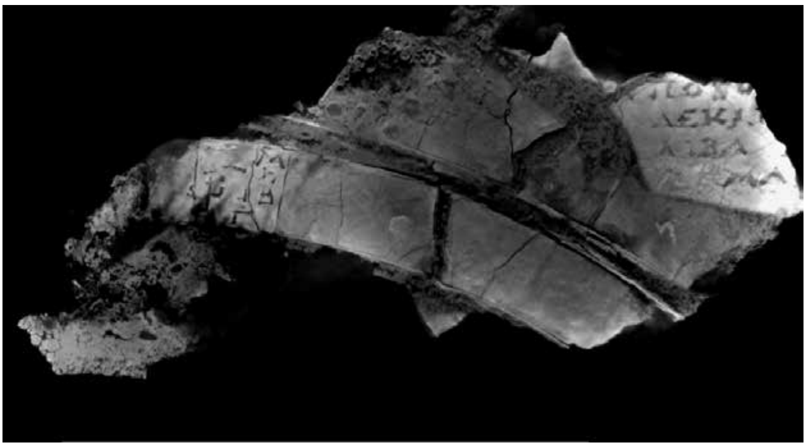

Figure 4.3 : *Fragment E, CT composite image*
(Image: Antikythera Mechanism Research Project)

Fragment F (Fig. 4.4), 80 mm height, 94 mm width, 35 mm thickness) preserves another part of the Saros Dial and the surrounding Back Plate, both of which are entirely concealed by a layer of patina. Adhering to part of the inscribed face is a small piece from the corner of a metal plate with a sliding catch similar to the one preserved in Fragment C.[12] Part of the Mechanism's containing frame is also present. Fragment F was originally situated immediately below Fragment A, to which it would have been rather precariously attached, but it had broken off before the 1902 discovery and was not identified in the Museum's

11 The Price-Kalligas correspondence (comprising three letters from Kalligas and two from Price, 1976-1978) is preserved at the Adler Planetarium, Chicago. Price mistakenly thought that Fragment E adjoined the top of Fragment B, at the top of the original Mechanism. The first published description of Fragment E is in Wright 2005, 9; Wright determined its correct original location.

12 See IAM 3.2.

store until it was discovered by M. Zafeiropoulou in April, 2005.[13] The inscriptions are only visible by way of CT.

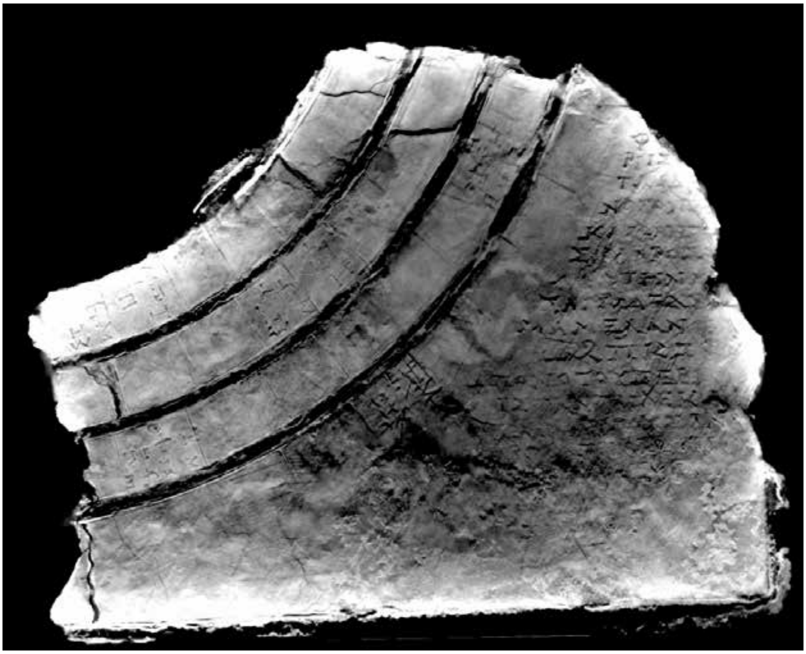

Figure 4.4 : *Fragment F, CT composite image*
(Image: Antikythera Mechanism Research Project)

13 Zafeiropoulou 2006, 830-831.

Two small platelike fragments, numbered 24 (29 mm height, 13 mm width) and 25 (21 mm height, 19 mm width), are part of a layer of accreted matter that originally lay against the Back Plate on A (Fig. 4.5). They preserve mirror-reversed "offset" impressions of parts of the Back Plate Inscription and the scale inscriptions of the Saros Dial, and in addition a bit of the surface of the Back Plate itself adheres to Fragment 25.

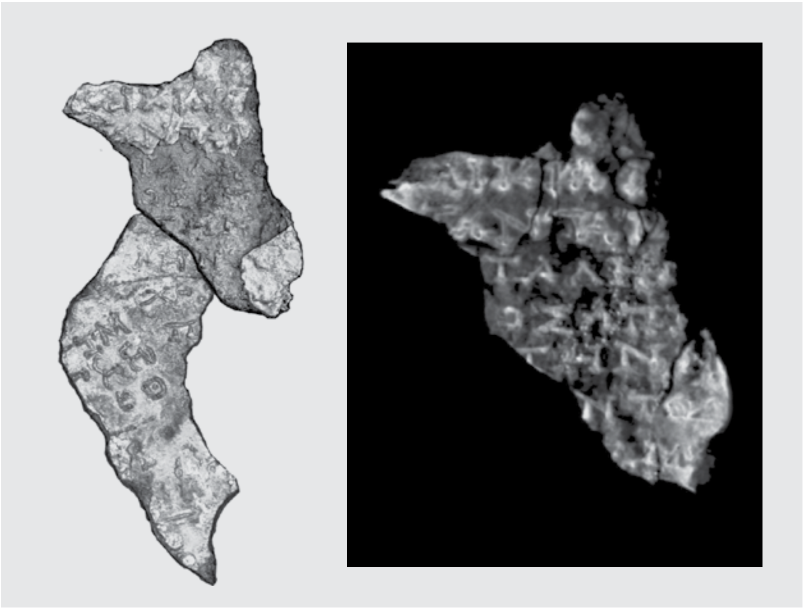

Figure 4.5: *(Left) Fragments 24 and 25, image from PTM ak2a and ak2b with diffuse gain; (right) Fragment 25, CT composite image*
(Images: Antikythera Mechanism Research Project)

4.3 Previous transcriptions and study of the Back Plate Inscription

Fragment A was one of the original two or three fragments to be accidentally discovered at the National Archeological Museum on May 18 or 20 (Julian), 1902.[14] In the condition in which it was found, only the top six or so lines of the Back Plate Inscription were exposed, while the remainder (as well as the Saros Dial scales) were hidden behind a layer of accreted matter, as can be seen in the photograph of A-2 in Svoronos's 1903 publication of the wreck.[15] When a group of archeologists including Gavriel Vyzantinos examined Fragment A on May 21 with the aid of a lens, only a few letters, including the unrecognizable word fragments INON (in the present line 3) and ΤΩΝ (likely a misreading of TAN in the present line 5) could be read, as reported in two Athens newspapers, *Σκρίπ* and *Νέον Ἄστυ* on May 22.[16] Attention soon shifted decisively to the mirror-writing inscription on B-1, which was seen to contain identifiable vocabulary relating to astronomy, and no further readings from A-2 were reported until Periklis Rediadis's report on the Mechanism incorporated in Svoronos's book. In its Greek edition, a few letters on five lines, credited to Svoronos and corresponding to lines 1-3 and 5-6 of the present lineation, are erroneously said to be inscribed on C-1.[17] The German edition has the identical transcription, but assigns it to its correct place on A-2.[18] The longest stretch of letters that Svoronos thought he was able to read was the sequence IKOMA in line 2, of which only the first two letters are correct, and not one complete word could be guessed at.

The layer covering the rest of the inscription was separated from A-2 during the conservation work of around 1905; two pieces of this layer survive, the present Fragments 24 and 25, which bear mirror-writing impressions of parts of the Back Plate Inscription and the Saros Dial scale inscriptions that exactly match the engraved text on A. A photograph of A-2 taken by Georg Karo for Albert Rehm in October, 1905, though none too clear, shows the entire inscribed area as it is now preserved.[19] A later photograph in Rehm's collection, believed to date from 1918, catches more detail, and hints that parts of the inscription were slightly more legible then than they are now. During his visits to Athens in 1905 and 1906 Rehm must have seen more of the inscription than Svoronos had, but if he made a fuller transcription if it, it has not come to light.

14 See IAM 2.1 for the history of discovery and conservation of the fragments.

15 Svoronos 1903a and 1903b, plate 10.

16 "Αἱ ἀρχαιότητες τῶν Ἀντικυθήρων," *Σκρίπ* no. 2429, May 22, 1902: 3; "Δύο ἐνεπίγραφα τεμάχια ἀπὸ τὰ Ἀντικύθηρα", *Νέον Ἄστυ* no. 162, May 22, 1902: 2.

17 Svoronos 1903a, 46.

18 Svoronos 1903b, 45.

19 Bayerische Staatsbibliothek, Rehmiana III/9.

Ioannis Theofanidis published transcriptions of parts of lines 12-18 in his encyclopedia article on the voyages of St. Paul and in his 1934 paper on the Mechanism, and he made the happy guess that ΩΤΗΝ in line 14 was the end of the wind name Ἀπηλιώτην, signifying either the East Wind or the direction due east.[20] Although his restorations of other bits of words in these lines as wind names have turned out to be false, such names do occur intermittently in the rest of the inscription. Theofanidis believed that the plate bearing the inscription was extraneous to the Mechanism and merely stuck on it, and that it was a remnant of a circular diagram showing the directions of the rising and setting points of stars on the horizon as an aid to navigation; under the influence of this hypothesis, his drawings misrepresent the lines of text as fanning out from a center point rather than running along parallel lines.

Fragment 24 was known to Theofanidis, who gave a transcription of it in his encyclopedia article.[21] Surprisingly, he did not recognize that it matched part of the inscription on A-2, the transcription of which was given immediately above.

In 1958 Derek de Solla Price and George Stamires studied the Mechanism's fragments (which had undergone another round of conservation in 1953); the transcription of the Back Plate Inscription that Price published in 1974 was presumably based on Stamires's work, since Price did not have sufficient knowledge of Greek to read or interpret the more extended inscriptions.[22] This was a more comprehensive transcription than any that had preceded it, with parts of lines 1-6 and 10-18 represented; roughly three quarters of the letters agree with the readings offered in the present paper. Stamires and Price were able to verify Theofanidis's Ἀπηλιώτην by reading several letters of the beginning of the word on line 13; but this was the only complete word that they correctly read or restored. While dismissing Theofanidis's other restorations of wind names, Price introduced a new false restoration, Ἰάπυγος, "West-northwest Wind," in lines 16-17.[23] He confessed his inability to explain the purpose of the direction references.

20 Theofanidis [1927-1930], "98" [correct pagination: 90] and 1934, 145. In the former article, "99" [correct pagination: 91] he repeats Svoronos's transcription of lines 1-3 and 5-6, saying these lines were formerly on a layer of material on Fragment C that had been removed to expose the parapegma inscription. Thus he was relying on Svoronos 1903a and unaware of the correction in Svoronos 1903b; but it is strange that he did not notice that these lines are actually on Fragment A, right above the ones that he himself transcribed. In the 1934 paper he makes no mention of the upper lines.

21 Theofanidis [1927-1930], "98" [correct pagination: 90]. It does not appear to be mentioned in Theofanidis 1934.

22 Price 1974, 48 and 50-51.

23 The file of Price's notes on the inscriptions kept at the Adler Planetarium, Chicago strongly suggests that Price introduced this restoration at a late stage, probably after his collaboration with Stamires had ceased.

In his 1959 *Scientific American* article, Price provided drawings of the portions of the Back Plate on B-1 and A-2.[24] The drawing of B-1 shows the cells of the Metonic Dial scale, with attempts to transcribe a few letters in eight of the cells. The circular outline of the Games Dial and its quadrant divisions is also shown, though it lies entirely behind the accretion layer with the Back Cover Inscription offsets; Price must have managed to see it by looking obliquely into the narrow gap between the Back Plate and the accretion layer.[25] The only indication he gives of inscribed text on the Games Dial is a sigma near the bottom of its lower left quadrant, which does not seem to correspond to any of the actual inscriptions.[26] On A-2 Price's drawing shows the cells of the Saros Dial, with incomplete but fairly good copies of the glyphs in cells 125, 178, and 184, and in the text of the article he correctly identifies the notations signifying Sun, Moon, and numbered hours.[27] He also shows the subsidiary Exeligmos Dial with the eta inscribed in its lower left sector, though the sector divisions are not drawn. Surprisingly, the corresponding figure in *Gears from the Greeks* shows fewer cell inscriptions on the Metonic dial, while the transcriptions of the three cells of the Saros Dial with glyphs are different from their 1959 versions and on the whole less accurate.[28]

On one page of his manuscript notes on the Mechanism's inscriptions Price drew a copy of Fragment 24 and noted its correspondence to the inscription on A, but in *Gears from the Greeks* he did not mention Fragment 24 at all. Price's 1958 photographs of the Mechanism's fragments show both 24 and 25, but he does not appear to have taken any special notice of 25.[29]

The paper on the Mechanism published in 2006 by the Antikythera Mechanism Research Project (AMRP) includes as part of its supplementary material a new provisional text of the Back Plate Inscription.[30] For the part preserved on A-2, this text follows Stamires-Price fairly closely, though adding a small number of new letters and correctly reverting in line 3 to the 1902-1903 reading INON (Stamires and Price apparently thought they saw HΛION, "Sun," with the lambda and iota fused). Moreover, through study of CT volumes, the AMRP

24 Price 1959, 64.

25 See also Wright 2005, 11, who reports being able to see only the upper left part of the circle with parts of two of the radii, as well as traces of dial inscriptions visible in tomographic images.

26 The sigma also appears in the drawing of B-1 in Price 1974, 17, Fig. 7. In the 1959 drawing the Games Dial is shown as a pair of concentric circles, whereas the 1974 drawing correctly shows only one circle.

27 Price 1959, 64-65.

28 Price 1974, 17, Fig. 7.

29 Price's collection of photographs relating to the Mechanism as well as his file of notes on the inscriptions are at the Adler Planetarium, Chicago.

30 Freeth et al. 2006, Supplementary Information 9-10.

researchers were able to add readings from inside Fragment E, which yielded earlier portions of lines 5-8 (though due to a slight misalignment of the fragments they were erroneously assigned to lines 4-7), and Fragment F, which yielded an entirely new run of thirteen lines of the inscription some distance below the part preserved in A. Over the entire inscription, about five letters out of six read in 2006 agree with our readings.

The AMRP researchers correctly read and recognized two new wind names in addition to retaining Theofanidis's correct Ἀπηλιώτην and Price's incorrect Ἰάπυγος, namely Λίβα, "West Wind," in Fragment E, line 6, and Νότον/Νότου, "South Wind," in Fragment F, lines 5 and 12. Unclear CT images misled them into reading two place names, Φάρος, "Pharos" (Fragment F, line 7) and Ἱσπανίας, "Spain" (Fragment F, line 13). Pointing out that the solar eclipses are highly dependent on geographical location, and that ancient eclipse observations often took note of wind directions during the eclipse —and perhaps also tacitly reasoning from the location of the inscription next to the eclipse spiral — the researchers suggested that the inscription had something to do with eclipses.

The 2006 paper also included provisional transcriptions of sixteen glyphs of the Saros Dial scale, relying on CT for those in Fragments E, F, and the parts of A hidden behind the accretion layer.[31] These were the first published transcriptions to show the index letters, though their function was not yet understood. The AMRP researchers were the first to identify the glyphs as indications that eclipses of the Sun or Moon could occur in the months corresponding to the inscribed cells, and they conjectured (unaware that Price had partially anticipated them) that the glyphs also gave a prediction of the time of eclipse in seasonal hours.

In 2008 a group of researchers associated with the AMRP published a second paper devoted to the Back Dial Inscriptions.[32] The revised transcriptions of the Saros Dial glyphs now extended to eighteen cells, and the numerals of the Exeligmos Dial were described and explained as time corrections for the predicted eclipse times. The index letters were explained for the first time, and on their basis a revised conjectural reconstruction of the distribution of glyphs was presented. This paper also provided the first transcriptions of the Metonic Dial and Games Dial inscriptions (aside from the few letters that Price copied). The calendar of the Metonic Dial scale was identified as that of Corinth, and a conjectural restoration of the entire calendrical scale was offered.

Meanwhile in 2007, Yanis Bitsakis and Emmanouel Georgoudakis (then of the Cultural Foundation of the National Bank of Greece, Center for History and Palaeography), who had undertaken a revision of the reading of the Back Plate Inscription, discovered in the part of

---

31 Freeth *et al.* 2006, 589, Fig. 4 and Supplementary Information 5. In this paper the Saros Dial's spiral was incorrectly reconstructed with its beginning and end at the bottom.

32 Freeth, Jones, Steele, & Bitsakis 2008.

the inscription in Fragment F terminology relating to colors, and on the basis of this as well as the expressions previously read relating to directions, Bitsakis identified the inscription as an eclipse description text. Comparing their readings with his own (from PTM) of the inscription on Fragment A, Alexander Jones established that the inscription comprised a series of paragraphs with repetitive structure, and conjectured that these paragraphs were linked to groups of the eclipse predictions in the Saros Dial scale by means of sets of index letters. Bitsakis and Jones produced an augmented and substantially improved transcription of the entire Back Plate Inscription in 2009. This transcription and the findings concerning the contents and structure of the inscription provided the foundations for the treatment of the Saros Dial and Back Plate Inscriptions in the present paper, which was drafted in 2012.

An extensive study of the eclipse predictions of the Mechanism was published by Tony Freeth in 2014.[33] This paper included revised copies of the glyphs as well as a transcription of the Back Plate Inscription. The latter was prepared by Charles Crowther (Centre for the Study of Ancient Documents, Oxford) on the basis of images and tracings provided to him by Freeth.[34]

---

33 Freeth 2014.

34 Freeth 2014, Note S2. Dr. Freeth had been provided by Bitsakis and Jones with their transcriptions and translations of the Back Plate Inscription in 2009 and 2012; the 2012 version differs in only minor details from Dr. Crowther's transcription and translation, made in November 2013 (according to personal communication from Dr. Crowther). In addition to its original contributions to the subject, Freeth 2014 presents several research findings relating to the Mechanism's eclipse inscriptions that had been communicated to Dr. Freeth by Bitsakis and Jones between 2009 and 2012. These include the fundamental identification of the Back Plate Inscription as eclipse descriptions organized in structurally repetitive paragraphs with statements about colors and changing directions, the correct alignment of the partial lines in Fragments E and A, the correlation of the paragraphs with the Saros Dial glyphs through groups of index letters, the reference of all the surviving paragraphs to solar eclipses, the probable division of the complete inscription into two halves pertaining respectively to lunar and solar eclipses, and the fact that all eclipses grouped together in each paragraph had the Moon within fixed zones of elongation from one of the lunar nodes. Further findings relating to the Saros Dial glyphs communicated to Dr. Freeth in 2012 include demonstrations that the eclipse times in the glyphs probably indicate the times of true syzygy, that the intervals between such times can be approximately modelled as the sum of periodic solar and lunar components, and that the Saros Dial was normed so that the Moon was close to apogee at its first Full Moon, aligning the dial with the presumed marks for the Full Moon Cycle inscribed inside the Saros Dial. Freeth 2014 makes no mention of either Bitsakis or Jones except as authors of published works.

4.4 Transcriptions and translations

i. Inscriptions in the cells of the Metonic Dial

All remains of the Metonic Dial are in Fragment B, and have been read from CT. For discussion, see section 5.

Transcription and translation

<table>
<tr><th>Cell</th><th></th><th></th></tr>
<tr><td>1</td><td>(ἔτος) α ´ | Φ̣[οινι-] | κ̣αῖος̣</td><td>Year 1 Phoinikaios</td></tr>
<tr><td>2</td><td>Κρα- | νε̣ῖ- | ος̣</td><td>Kraneios</td></tr>
<tr><td>3</td><td>Λ[ανο-] | τ̣[ρόπι-] | [ος]</td><td>Lanotropios</td></tr>
<tr><td>31</td><td>[Δωδ]ε- | [κα-] | [τεύ]ς</td><td>Dodekateus</td></tr>
<tr><td>32</td><td>Εὔ- | κλει- | ος</td><td>Eukleios</td></tr>
<tr><td>33</td><td>Ἀρτε- | μίσι- | ος</td><td>Artemisios</td></tr>
<tr><td>34</td><td>Ψ̣υ̣- | δ̣ρ̣ε- | [ύ]ς̣</td><td>Psydreus</td></tr>
<tr><td>35</td><td>no legible text</td><td>[Gameilios]</td></tr>
<tr><td>36</td><td>Ἀγρι- | άνι- | ο̣ς</td><td>Agrianios</td></tr>
<tr><td>37</td><td>Π̣ά̣- | [να]- | μος</td><td>Panamos</td></tr>
<tr><td>38</td><td>Ἀπελ- | λαῖος̣</td><td>Apellaios</td></tr>
<tr><td>39</td><td>(ἔτος) δ ´ | Φ̣[οι]ν[ι-] | [καῖ]ο̣ς</td><td>Year 4 Phoinikaios</td></tr>
<tr><td>40</td><td>Κ̣ρ̣α- | ν̣ε[ῖ-] | ο̣ς</td><td>Kraneios</td></tr>
<tr><td>41</td><td>Λ̣ανο- | τρό- | πιος</td><td>Lanotropios</td></tr>
<tr><td>42</td><td>Μαχα- | νεύς</td><td>Machaneus</td></tr>
<tr><td>43</td><td>Δωδε- | κα- | τεύς</td><td>Dodekateus</td></tr>
<tr><td>44</td><td>Εὔ- | κ̣λ̣ει- | ος̣</td><td>Eukleios</td></tr>
<tr><td>45</td><td>Ἀρτε- | μίσι- | ος</td><td>Artemisios</td></tr>
<tr><td>46</td><td>Ψυ- | δρεύς</td><td>Psydreus</td></tr>
<tr><td>47</td><td>Γαμε[ί]- | λιος̣</td><td>Gameilios</td></tr>
<tr><td>48</td><td>Ἀγρι- | άνιος</td><td>Agrianios</td></tr>
<tr><td>49</td><td>Πάνα- | μος</td><td>Panamos</td></tr>
<tr><td>79</td><td>Μαχα- | νεύς</td><td>Machaneus</td></tr>
<tr><td>80</td><td>Δωδε- | κ̣α̣τ̣ε- | ύ̣ς̣</td><td>Dodekateus</td></tr>
<tr><td>81</td><td>Εὔ- | κλε̣[ι-] | ος</td><td>Eukleios</td></tr>
<tr><td>82</td><td>Ἀ̣ρ̣τ̣ε- | μ̣[ίσι-] | ος</td><td>Artemisios</td></tr>
<tr><td>83</td><td>no text visible</td><td>[Psydreus]</td></tr>
<tr><td>84</td><td>[ ] | [ ] | ος</td><td>[Gameili]os</td></tr>
<tr><td>85</td><td>no text visible</td><td>[Agrianios]</td></tr>
<tr><td>86</td><td>Π̣ά̣ν̣α̣- | μ̣[ο]ς̣</td><td>Panamos</td></tr>
</table>

<table>
<tr><td>87</td><td>Ἀ̣π̣ελ- | λαῖος</td><td>Apellaios</td></tr>
<tr><td>88</td><td>(ἔτος) η ´ | Φοινι- | καῖο̣ς̣</td><td>Year 8 Phoinikaios</td></tr>
<tr><td>89</td><td>Κρα- | νεῖ- | ος</td><td>Kraneios</td></tr>
<tr><td>90</td><td>Λ̣α̣ν̣ο- | τρ̣[ό]πι- | ος</td><td>Lanotropios</td></tr>
<tr><td>91</td><td>Μαχα- | νεύς</td><td>Machaneus</td></tr>
<tr><td>92</td><td>Δωδε- | κατε- | ύς</td><td>Dodekateus</td></tr>
<tr><td>93</td><td>Εὔ- | κλει- | ο̣ς</td><td>Eukleios</td></tr>
<tr><td>94</td><td>Ἀρτε- | μίσι- | ος</td><td>Artemisios</td></tr>
<tr><td>95</td><td>Ψυ- | δρεύς</td><td>Psydreus</td></tr>
<tr><td>96</td><td>Γαμεί- | λιος</td><td>Gameilios</td></tr>
<tr><td>97</td><td>Ἀγ̣[ρι-] | άν[ιος]</td><td>Agrianios</td></tr>
<tr><td>127</td><td>Λα[νο-] | [τ]ρ̣ό̣[πι-] | ο[ς]</td><td>Lanotropios</td></tr>
<tr><td>128</td><td>Μ[α]χα- | [νεύς]</td><td>Machaneus</td></tr>
<tr><td>129</td><td>Μα̣χα- | νε̣ύ̣ς</td><td>Machaneus</td></tr>
<tr><td>130</td><td>Δω̣[δε-] | κα[τ]ε̣- | ύ̣[ς]</td><td>Dodekateus</td></tr>
<tr><td>131</td><td>Ε̣ὔ̣- | κλει- | ος</td><td>Eukleios</td></tr>
<tr><td>132</td><td>Ἀρ̣[τε-] | μίσι- | [ο]ς̣</td><td>Artemisios</td></tr>
<tr><td>133</td><td>[Ψυ-] | δρεύς</td><td>Psydreus</td></tr>
<tr><td>134</td><td>[Γα]μ[εί-] | λ̣ι̣ος</td><td>Gameilios</td></tr>
<tr><td>135</td><td>Ἀγρι- | άνιος</td><td>Agrianios</td></tr>
<tr><td>136</td><td>Πάνα- | μος</td><td>Panamos</td></tr>
<tr><td>137</td><td>Ἀπελ- | λαῖος</td><td>Apellaios</td></tr>
<tr><td>138</td><td>(ἔτος) ιβ ´ | Φοινι- | καῖος</td><td>Year 12 Phoinikaios</td></tr>
<tr><td>139</td><td>Κρα̣ν̣ε̣[ῖ-] | ος</td><td>Kraneios</td></tr>
<tr><td>140</td><td>Λ̣α̣ν̣ο̣- | [τρόπιος]</td><td>Lanotropios</td></tr>
<tr><td>141</td><td>Μαχα- | ν̣ε̣ύς</td><td>Machaneus</td></tr>
<tr><td>142</td><td>Δωδε- | κατεύς</td><td>Dodekateus</td></tr>
<tr><td>143</td><td>Ε[ὔ-] | κ̣λ̣[ειος]</td><td>Eukleios</td></tr>
<tr><td>174</td><td>no text visible</td><td>[Apellaios]</td></tr>
<tr><td>175</td><td>[(ἔτος) ι]ε ´ | Φ̣[οι]ν̣ι̣- | καῖος</td><td>Year 15 Phoinikaios</td></tr>
<tr><td>176</td><td>Κρα- | νε̣ῖο̣ς</td><td>Kraneios</td></tr>
<tr><td>177</td><td>[Λα]ν̣ο̣ | [τρό]π̣[ι-] | [ος]</td><td>Lanotropios</td></tr>
<tr><td>178</td><td>Μαχα- | νεύ̣ς̣</td><td>Machaneus</td></tr>
<tr><td>179</td><td>Δωδ̣ε̣- | κ̣α̣τ̣ε̣ύ̣ς</td><td>Dodekateus</td></tr>
<tr><td>180</td><td>Εὔ̣- | κ̣λ̣ειος</td><td>Eukleios</td></tr>
<tr><td>181</td><td>Ἀρτε- | μίσιος</td><td>Artemisios</td></tr>
<tr><td>182</td><td>Ψ̣υ- | [δρ]εύς</td><td>Psydreus</td></tr>
<tr><td>183</td><td>Γαμεί- | λιος</td><td>Gameilios</td></tr>
<tr><td>184</td><td>Ἀ[γριά-] | νιος</td><td>Agrianios</td></tr>
<tr><td>185</td><td>[Πά]να- | μος</td><td>Panamos</td></tr>
</table>

186	Ἀπελ- | λαῖος	Apellaios
187	(ἔτος) ι̣ϛ̣ | [Φοινι-] | κ̣[αῖος]	Year 16 Phoinikaios
188	Κ̣ρ̣α̣- | [νεῖος]	Kraneios
189	Λαν̣[ο-] | τρ̣όπι- | [ο]ς	Lanotropios
225	[ ] | ος	[Kranei]os
226	[Λανοτρό-] | π̣ι̣ο̣ς	Lanotropios
227	[Μ]α̣[χα-] | νεύς	Machaneus
234	[Πά-] | [ναμ]ος	Panamos
235	Ἀπελ- | λαῖ̣ο̣ς	Apellaios

Apparatus

1 (ἔτος): L (likewise 39, 88, 138, 187) | Φ̣: faint and indistinct | κ̣: bottom half of letter, indistinct | ϛ̣: letter straddles division line between cells 1 and 2 | 2 ε̣: faint and distorted | ϛ̣: indistinct | 3 τ̣: faint | 34 Ψυ̣: faint | δ̣ρ̣: faint | ϛ̣: faint | 36 ο̣: indistinct | 37 Π̣α̣: indistinct | 39 Φ̣: faint | ο̣: faint | 40 Κ̣ρ̣: faint | ν̣: faint | ο̣: faint | 41 Λ̣: indistinct | 44 κ̣λ̣: faint | ϛ̣: indistinct | 47 ϛ̣: indistinct | 80 κ̣α̣τ̣: faint | υ̣ϛ̣: faint | 81 ε̣: horizontal stroke at baseline | 82 Α̣ρ̣τ̣: indistinct | μ̣: bottom half of letter | 86 Π̣α̣ν̣α̣: indistinct | μ̣[ο]ϛ̣: indistinct | 87 Α̣π̣: faint | 88 ο̣ϛ̣: indistinct | 90 Λ̣α̣ν̣: indistinct | ρ̣: indistinct | ο̣: indistinct | 93 ο̣: indistinct | 97 γ̣: complete, along edge | 127 ρ̣ο̣: indistinct | 129 α̣: indistinct | ε̣υ̣: indistinct | 130 ω̣: indistinct | ε̣: indistinct | υ̣: indistinct | 131 Ε̣υ̣ indistinct | 132 ρ̣: bottom of vertical | ϛ̣: indistinct, along bottom edge of cell | 134 λ̣ι̣: very faint | 139 α̣ν̣ε̣: faint | 140 Λ̣α̣ν̣ο̣ very faint | 141 ν̣ε̣: indistinct | 143 κ̣λ̣: faint and indistinct | 175 Φ̣: faint | ν̣ι̣: indistinct | 176 ι̣ο̣ϛ indistinct | 177 ν̣ο̣: top parts of letters | π̣: indistinct | 178 υ̣ϛ̣: indistinct | 179 δ̣ε̣: indistinct | κ̣α̣τ̣ε̣υ̣: indistinct | 180 υ̣: indistinct | κ̣λ̣: indistinct | 182 Ψ̣: right half of letter | 187 ι̣: indistinct | ϛ̣: left and top of symbol | κ̣: indistinct | 188 Κ̣ρ̣α̣: indistinct | 189 ν̣: lower half of letter | ρ̣: indistinct | 226 π̣: faint | ι̣ο̣: indistinct | 227 α̣: indistinct | 235 ι̣ο̣: indistinct

ii. Inscriptions adjacent to the innermost turn of the Metonic Dial

The remains of these inscriptions are in Fragment B, and were read from CT. For discussion, see section 4.5.

Transcription and translation
Cell

e1	α´	1st
e33	β̣´	2nd
e35	ϛ´	6th
e37	ια´	11th

e39	ιε ΄	15th
e41	ιθ ΄	19th
e43	κγ ΄	23rd
e45	κζ ΄	27th

Apparatus
e33 β̣: very faint

iii. Inscriptions of the Games Dial

The dial survives complete in Fragment B, and has been read from CT. For discussion, see section 4.5.

Transcription and translation

Sector	*Location*		
1	interior	(ἔτος) α ΄.	Year 1
	exterior	Ἴσθμια | Ὀλύμπ̣ι̣α̣	Isthmians | Olympics
2	interior	(ἔτος) β ΄.	Year 2
	exterior	Νέμε̣α̣ | Νᾶα	Nemeans | Naa
3	interior	(ἔτος) γ ΄.	Year 3
	exterior	Ἴσ[θ]μ̣ια | Π̣ύθ̣ια	Isthmians | Pythians
4	interior	(ἔτος) δ ΄.	Year 4
	exterior	Νέμεα | Ἁ̣λ̣ιεῖα	Nemeans | Halieia

Apparatus
1 interior (ἔτος): L (likewise 2, 3, 4) | exterior π̣ι̣α̣: indistinct | 2 exterior ε̣α̣: indistinct | 3 exterior μ̣: indistinct | Π̣: right half of letter, indistinct | ι̣: indistinct | 4 exterior Α̣: right descending diagonal stroke | ι̣: indistinct

iv. Inscriptions in the cells of the Saros Dial

The inscriptions ("glyphs") in cells 61, 114, 119 (except for the last letter of its second line) and 172 are preserved in Fragment E and were read from CT. Those in cells 20, 25, 26, 78, 79, 131, 137, and 190 are in Fragment F and were read from CT. The remaining preserved glyphs are in Fragment A. The glyph in cell 13 was read from CT and from a photograph by Emile Seraf (see the "comments on readings" below). Those in cells 8, 67, 72, 119 (last letter of line 2), and 120 were read from CT, and those in cells 125, 178, and 184 from the PTMs. For the interpretation of the glyphs, see section 4.7 below.

Transcription

Cell

8 Σ̣ . |̣ . . | Β
13 Η | ὥρ(ạ) α ´. | Γ
20 Σ [ ] | ὥρ(ạ) ς ´. | Ε
25 Η | ὥρ(ạ) ς ´. | Ζ
26 Σ ἡμ(έρας) | ὥρ(ạ) ζ ´. | Ḥ

61 Σ [ ] | [ ] | [Ο]
67 Σ [ ] | ὥ̣ρ̣(ạ) η ´ | Π
72 Η ν̣υ̣(κτὸς) | ὥ̣ρ̣(ạ) . ´. | Ρ
78 Η | ὥρ(ạ) α ´. | Τ
79 Σ ἡμ(έρας) | ὥρ(ạ) ι ´. | Υ

114 Σ ἡμ(έρας) | ὥρ(ạ) ιβ ´. | Γ̅
119 Η νυ(κτὸς) | ὥρ(ạ) ιβ ´. | Δ̅
120 Σ ἡμ(έρας) | ὥρ(ạ) . ´. | Ε̣̅
125 Σ ἡμ̣(έρας) ὥ̣ρ̣(ạ) η ´. | Η ὥρ(ạ) γ ´. | Ζ̅
131 Σ ὥρ(ạ) β ´. | Η νυ(κτὸς) ὥρ(ạ) θ ´. | Η̅
137 Σ ἡμ(έρας) ὥρ(ạ) ε ´. | Η ὥρ(ạ) ιβ ´. | Θ̅

172 Σ ὥρ(ạ) ς ´. | Η ὥρ(ạ) ιβ ´. | Π̅
178 Σ ὥρ(ạ) θ ´. | Η ὥρ(ạ) θ ´. | Ρ̅
184 Σ ἡμ(έρας) ὥρ(ạ) δ ´. | Ḥ ὥρ(ạ) α ´. | Σ̣̅
190 Σ ἡμ(έρας) | ὥρ(ạ) θ ´. | Τ̅

Translation

Cell

8 Moon, ... Β
13 Sun, 1st hour. Γ
20 Moon, [ ] 6th hour. Ε
25 Sun, 6th hour. Ζ
26 Moon, 7th hour of day. Η

61 Moon, ... [Ο]
67 Moon, [ ] 8th hour. Π
72 Sun, ... hour of night. Ρ
78 Sun, 1st(?) hour of day. Τ
79 Moon, 10th hour of day. Υ
114 Moon, 12th hour of day. Γ̅
119 Sun, 12th hour of night. Δ̅
120 Moon, ... hour of day. Ε̅

125 Moon, 8th hour of day. Sun, 3rd hour of day. $\overline{Z}$
131 Moon, 2nd hour. Sun, 9th hour of night. $\overline{H}$
137 Moon, 5th hour of day. Sun, 12th hour. $\overline{\Theta}$

172 Moon, 6th hour. Sun, 12th hour. $\overline{\Pi}$
178 Moon, 9th hour. Sun, 9th hour. $\overline{P}$
184 Moon, 4th hour of day. Sun, 1st hour. $\overline{\Sigma}$
190 Moon, 9th hour of day. $\overline{T}$

Apparatus

Throughout these inscriptions, ἡμέρας is represented by a mu suspended directly above an eta; νυκτός is represented by an upsilon suspended above a nu; and ὥρᾳ is represented by the digraph ϕ.

8 Σ̣ left side blurry, followed by indistinct traces to its right and on the following line | 20 right of Σ, possibly a small raised mu to the right of the sigma but no visible trace of an eta below it | 26 Ḥ: indistinct, scarcely visible trace | 67 η̣ blurry | 72 ̣: apparently the left half of epsilon or beta, the remainder distorted and indistinct | 78 an apparent mark to the left of alpha is probably not a letter | 120 ̣: extremely faint and indistinct traces | 125 η^2 is written to the right of the division between cells 125 and 126

Comments on readings

8: This glyph has not previously been reported. All plausible reconstructions of the distribution of glyphs require a glyph in this cell, either for just a lunar eclipse possibility or for both lunar and solar eclipse possibilities (see below, section 7). Hence the sigma at the beginning of the top line, though blurred in the CT, is assured. The index letter beta in the third line is also in agreement with all reconstructions. CT volume A6, which gives the best images for this cell, appears to show at least two indistinct letters or symbols to the right of the sigma and at least two letters or symbols in the second line, though the traces become increasingly faint in both lines towards the right. These observations favor identifying the glyph as both lunar and solar.

13: The glyph of this cell survives but has been partially obscured, probably as a consequence of the joining to it of a small fragment consisting of part of this turn of the spiral scale and a portion of the accretion layer bearing offsets of the Back Cover Inscription. This fragment had broken off Fragment A before Price's time and was reattached in the 1970s. No significant part of cell 14, which ought to have been inscribed with a glyph according to all reconstructed schemes, survives. The cell that now adjoins cell 13 is in fact cell 15, so that the reattached fragment is not quite in its proper position, as can be confirmed by comparing the inscription offsets with photographs from the early 20th century, when the accretion layer in this region of Fragment A was intact. The glyph of cell 13 has previously been transcribed on the basis of the CT volumes, in which the hour numeral is visible as an apical letter, leaving it uncertain whether it is an alpha (1) or delta (4).[35] Our reading of cell 13 with a definite alpha is based on the very clear appearance of the glyph in an undated photograph (1950s to 1970s), one of a pair showing both sides of Fragments A, B, and C, taken by the archeological photographer Emile Seraf.[36]

20: A small mark is visible in CT to the right and above the sigma in the first line, close to a crack.[37] Although this could be reconciled with part of the raised mu of the abbreviation of ἡμέρας, there is no trace of an eta below; we conclude that this is an accidental feature rather than engraved lettering.

61: This glyph was not previously reported. Unfortunately, all that remains of it is the sigma at the beginning of the first line, whose presence was predicted by all plausible reconstructions of the glyph distribution.

67: This glyph was previously reported from extremely indistinct images, on the basis of which sigma at the beginning of the first line and pi as index letter were reported in agreement with all plausible reconstructions.[38] In both CT volumes A5 and A6, traces of the sigma are visible though the letter could probably not be recognized if it was not expected; however, at the beginning of the second line traces can be seen identifiable as the top part of the symbol for ὥρα̣, followed by a faint but distinct eta. The index letter pi is also distinct.

72: The hour numeral was previously reported as an eta, based on traces interpreted as the left vertical and left part of the mid-height horizontal strokes of that letter.[39] Closer examination of the cell in CT volume A5 (which provides clearer images for this region than A6) shows a vertical with what appear to be strokes going out from it to the right at top, mid height, and baseline; depending on the plane selected for viewing, the strokes either appear to continue horizontally rightwards as in an epsilon or to meet in indistinct loops as in beta. There is space for, but no clear trace of, an iota immediately preceding this letter. Hence beta (2), epsilon (5), or iota-beta (12) are credible readings.

35 Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 25; Freeth 2014, Fig. S13 and Note S4, 2.

36 The negative of this photograph was acquired with the rest of Seraf's collection by the Athens department of the Deutsches Archäologisches Institut, whom we thank for providing a scan.

37 We were alerted to this by C. Carman (personal communication).

38 Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 26; Freeth 2014, Fig. S13.

39 Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 26.

78: The second line was previously reported as a ὥρᾳ symbol (malformed on its right side) followed by a tiny raised νυκτός abbreviation and the numeral alpha (1).[40] This reading violates the normal syntax of the glyphs, according to which an indication of day or night, if present, precedes the ὥρᾳ symbol. In fact what was interpreted as the left vertical of the nu of νυ(κτός) is actually the right end of the ὥρᾳ symbol, *not* malformed, and we take the remaining mark between this symbol and the alpha to be an accidental feature.[41]

119: The cell is mostly preserved in Fragment E, but its rightmost portion is in A. Previously, only images and readings from the portion in E have been reported.[42] Since the hour numeral as preserved in E is an iota close by the break, it was assumed that the numeral could have been simply iota (10) or iota followed by alpha (11) or by beta (12). The last of these possibilities is proved correct by a beta in the appropriate position clearly visible in CT volume A5.

120: All that can be seen of the hour numeral is a faint and doubtful vertical stroke in volume A6, which would be consistent with any numeral except alpha (1), delta (4), or theta (9). The 2008 publication gave an "uncertain" reading of eta (8) in a rather low position; we consider this to be a phantom reading.[43] More recently, iota-beta (12) has been offered as "very uncertain."[44]

125: The hour numeral in the first line was read as eta (8) in the 2008 publication.[45] More recently beta (2) has been proposed on the basis of a blurry CT image.[46] We consider the eta to be certain on the basis of PTM ak48a and CT volume A6, both of which show the letter complete with all serifs.

172: In the 2008 publication the hour numeral in the first line was incorrectly read as epsilon (5).[47]

40 Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 26.

41 Similarly Freeth 2014, Note S4, 2.

42 Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 26; Freeth 2014, Fig. S13 and Note S4, 2.

43 Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 26; the reading is judged "highly dubious" by Freeth 2014, Note S4, 2.

44 Freeth 2014, Fig. S13 and Note S4, 2.

45 Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 27.

46 Freeth 2014, Fig. S13 and Note S4, 2.

47 Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 27; corrected in Freeth 2014, Fig. S13 and Note S4, 2.

v. Inscriptions of the Exeligmos Dial

The dial survives nearly complete in Fragment A; sector 2 was read from PTM, sector 3 from CT. For the interpretation of the inscribed numerals, see section 8 below.

Text and translation.

Sector		
2	η	8
3	ις	16

vi. Back Plate Inscription

The preserved text of lines 1-18 of the Back Plate Inscription, except for the leftmost portions of 5-8, are in Fragment A. Fragment 25 duplicates parts of lines 9-16 of the Back Plate Inscription (and actually has a bit of the surface of the Back Plate itself adhering to it at lines 15-16), while Fragment 24 duplicates parts of lines 14-17. The inscriptions in E preserve the beginnings of lines 5-8. The inscriptions in F preserve lines 19-36. It is unlikely that there existed any lines of the Back Plate Inscription lost in the interval between line 18 (in A) and line 19 (in F), where the right rim of the Saros Dial comes very close to the right edge of the plate. Much of this interval is present on A, and bears no detectable writing.

The mean baseline-to-baseline spacing of the Back Plate Inscription in Fragments A and F is approximately 3.0 mm. The average letter height is about 1.6 mm in Fragment A as measured from a photograph, but about 2.0 mm in Fragment F as measured from CT images. The interlinear space thus averages about 1.4 mm in Fragment A and about 1.0 mm in Fragment F. Average horizontal letter spacing, from the leftmost point of one letter to the leftmost point of the next is about 2.1 mm in both fragments, though with considerable (roughly ±15%) variation from line to line.

Text and translation

0	[ἀπὸ περιίσταν-]	[From... and they veer]
1	[ται δὲ καὶ κατα]λ̣ή̣γ̣ο[υσι]	[about and] end up
2	[πρὸς ̣ ̣ ̣ ̣ ̣ . μ]ικραί. τ̣[ὸ δὲ]	[towards.... S]mall. The
3	[χρῶμα ̣ ̣ ̣ ̣ ̣ .] ̣ ινον. *v*	[color] *uncertain*.
4	[ ]Ω̣ *v*	[ ]Ω(?)
5	ἀ̣πὸ βο[ρείου], π̣ε̣ρ̣ι̣ί̣σ̣ταντ[αι]	From *boreas*, and they veer about
6	δὲ κα̣ὶ [κατ]αλήγου̣σι πρ[ὸς]	and end up towards
7	λίβα. *v* μ̣[έ]σαι. τ[ὸ] δὲ χρῶ̣-	*lips*. [Inter]mediate. The co-
8	{μα}μα μ̣έλαν. *v*	lor black.
9	Α̣ *v* Ν *v* ̣ *v* Β̣ *v* Φ̣	A(?) N ... B(?) Φ(?)
10	ἀ̣πὸ θ̣ραικίαν, πε̣[ρι-]	From *thrakias*, and they veer
11	ίστανται δ̣[ὲ καὶ]	about and

12	καταλήγ̣ο̣[υσι]	end up
13	πρὸς ἀπηλι-	towards *apêli-*
14	ώτην. μ[εγά-]	*ôtês*. Large(?).
15	λην. τὸ δ̣ὲ̣	The
16	χρῶμα	color
17	πυ̣ρ̣[ρόν.]	fiery red.
18	ΖΘ̣̅Σ ̣ Χ̣	ΖΘ̅(?)Σ...Χ(?)
19	ἀπ̣̣[ὸ ζε-]	From *ze-*
20	φύ̣[ρου, πε-]	*phyros*, and they
21	ριίστ̣[αν-]	veer
22	ται δὲ [πρὸς]	about towards
23	νότον κ[αὶ]	*notos* and
24	καταλήγου̣-	end
25	σιν πρὸς ἀ[πη-]	up towards *apêli-*
26	λιώτην. μέ̣-	*ôtês*. Inter-
27	σαι. τὸ δὲ χρῶ̣-	mediate. The co-
28	μα μέλαν. *v*	lor black.
29	̣Λ̣Ξ̣(*symbol*)Π̅ΚΖΦ	̣Λ̣Ξ̣(symbol)Π̅ΚΖΦ
30	ἀπὸ νότου, περι-	From *notos*, and they veer
31	ἵστανται δὲ κα̣ὶ	about and
32	καταλήγουσιν	end up
33	πρὸς ἀπηλιώτην.	towards *apêliôtês*.
34	μ̣ι̣κ̣ρ̣αί. τὸ δὲ χρῶμ̣α̣	Small(?). The color
35	μέλαν. *v*	black.
36	*v* Τ *v* Η̅ *v* Θ *v* Ρ̅ *v* Ψ̣	Τ Η̅ Θ Ρ̅ Ψ(?)

Apparatus

1 λ̣η̣γ̣: left ascending diagonal and top part of descending diagonal of apical letter, then a serifed bottom of right vertical, then a vertical with bottom serif, meeting horizontal at top height that extends very slightly to the left and farther to the right | 2 τ̣: serifed left part of horizontal and serifed bottom part of vertical | 3 ̣ : trace at baseline along edge | 4 Ω̣: right half of large, very wide loop, with small gap at the top | 5 In ecthesis | α̣: bottom end of descending diagonal | π̣ε̣ρ̣ι̣: indistinct traces | σ̣: indistinct | 6 ι̣: vertical with serif at bottom, along edge | υ̣: indistinct | 7 *v*: one letter | μ̣: trace at baseline along edge | ω̣: left half of letter, indistinct | 8 {μα}: faint, presumably effaced | μ̣: complete but indistinct | 9 Α̣: apical letter with faint horizontal cross-stroke at mid height | ̣ : apparent ascending and descending strokes of apical letter | Β̣: small loop between mid and top height, traces below indistinct, to the right near baseline an indentation resembling the serifed right extremity of omega (possibly an accidental feature) | Φ̣: complete but distorted by damaged surface | 10 In ecthesis | α̣: faint apical letter | *l.* θραικίας | θ̣: indistinct | ε̣: vertical, indistinct | 11 δ̣: indistinct | 12 ο̣: left side of small loop, indistinct | 15 ε̣: indistinct | 17 ρ̣: indistinct | 18 Θ̣̅: most of a large loop well preserved (a large omicron cannot be ruled out), bar over letter | ̣ : indistinct nar-

row letter (iota or rho), pitted surface, possibly a trace of a bar over the letter | χ̣: complete but indistinct | 19 In ecthesis | π̣: left vertical (?), faint and indistinct | 20 υ̣: left descending diagonal and vertical with serif at bottom | 21 τ̣: trace at top level along edge | 24 υ̣: small, doubtful trace at top height along edge | 26 ε̣: indistinct traces at baseline along edge | 27 ω̣: indistinct, missing top of loop | 29 ̣: apical letter | Λ̣: faint | Ξ̣: apparently form with vertical cross-stroke, bottom horizontal with serifs, clear traces of bottom end of vertical and left end of top horizontal, faint traces of shorter middle horizontal | Μ̣: a faint trace of ascending diagonal with serif at bottom, possible faint traces to right | 30 In ecthesis | 31 ̣ι: faint | 34 ̣ι̣κρ̣: indistinct traces, with a break running through the presumed rho; (μ)έ̣σ̣(αι) cannot be ruled out | α̣: faint | 36 *v*$^{1-5}$: space for 1-2 letters | Ψ̣: faint and doubtful |

Comments on readings

1: Crowther[48] reports ̣ΙΤ̣Ο. The horizontal stroke of the second letter extends, so far as we can tell, only a little way to the left of the vertical, but further to the right than would be normal for tau; we believe gamma is the strongly preferable reading. What remains of the first letter is a vertical serifed at top and bottom with the edge of the surviving engraved surface immediately to its left. The combination of readings in lines 1-3, with a possible καταλήγουσιν in 1, a highly probable μικραί in 2, and a termination possible for a color adjective followed by vacant space in 3, provide a strong case for restoring lines 0-4 as a regularly structured paragraph of the inscription followed by a line of index letters, rather than the "introductory" section hesitantly suggested by Crowther.[49]

4: We believe this ought to be a line of index letters, but the one letter or symbol partially surviving is hard to identify. We agree with Crowther's observation that the loop appears to be too broad for omicron, and as he notes, it also has a slight gap at the top. A semblance of a vertical stroke descending from the loop is actually the edge of the break, though this could in principle have followed the right edge of an engraved stroke had there been one there. Phi is unlikely both because of the gap and because there is no trace of a serif where the descending vertical should have ended. This leaves as the only plausible candidate the cursive (open-topped) form of omega.

7: We are confident of μέσαι. Crowther reads [..]Ω̣Ε̣ΑΙ on the basis of CT, but raises the possibility that the supposed epsilon is actually a sigma so that (disregarding the doubtful omega) [μέ]σ̣αι would be possible. We see the entire sigma in PTM ak50a. The vacant space to the right

48 Crowther's transcription is the right part of Freeth 2014, 9, Fig. 8, supplemented by his epigraphic notes at Note S2, 2-3. Crowther's notes say nothing about the index letter lines 9, 18, 29, and 36, whereas their readings are discussed in detail by Freeth 2014, Fig. S6, so it would appear that these lines in Crowther's transcription are largely Freeth's readings and restorations.

49 Freeth 2014, S2, 2.

of λίβα accounts for the fact noted by Crowther that μέσαι would be shorter than the lacuna.

8: The engraver inscribed the beginning of line 5, the first line of this paragraph, in ecthesis (i.e. hanging indentation) as he did for the other paragraphs, and then continued with lines 6-8 having a straight left margin. After writing μα in this position, which brought the text right to the outer rim of the Saros Dial scale, he seems to have effaced the strokes and begun the line again immediately to the right of them.

9: Crowther reports ΝΛ̣̅Β̣Φ̣̅.[50] Freeth describes the last of these letters as "convincing" while indicating that the barred lambda and beta are only apparent if one is expecting to find these letters.[51] In PTM ak50a and CT volume A6 we see a likely alpha to the left of nu, the two sloping strokes of the presumed lambda (but no clear trace of a bar above), a plausible beta (or conceivably omega), and a convincing phi (with no visible bar).

10: The ungrammatical reading ἀπὸ θραικίαν is not in doubt. On Fragment A the alpha of -αν is damaged at the top while only the bottom of the left and right sides of nu survive, but Fragment 25 has clear offsets of both letters. Crowther reports θραικί[ου] π̣ε̣ρ̣ι̣-, but to the right of the epsilon the plate's surface has been lost to a depth probably greater than the engraving reached, and we can see no further traces.

11: Crowther reports δ̣ὲ̣ κ̣[αὶ], but again to the right of the delta the plate's surface is gone.

14: The traces of the mu, visible only in Fragment 25, support Crowther's restoration [μεγά-]|λην, "large." In the corresponding parts of the other passages we have adjectives indicating size in feminine nominative plural. We suspect that the accusative singular here is a copying error, likely through assimilation to the preceding ἀπηλιώτην.

18: Crowther reports ΖΘ̅Σ̣̅Ρ̣Χ̣. Freeth, however, indicates that no bar is visible over the theta, so the bar in the transcription is presumably conjectural.[52] In fact a bar *is* clearly visible in PTM ak49a, whereas we can see none on the damaged surface over the sigma. Freeth characterizes the identification of the letter reported as rho as "very likely" in contrast to the sigma and chi for which he merely claims consistency with the data.[53] On the basis of PTM ak49a we would say that sigma is certain and chi highly probable, but for the letter in between we can only see rough indentations in the surface and no definite remains of engraving. This letter, however, must have been narrow, either rho or iota.

50 In Crowther's transcription, index letters without bars are indicated by a subscript 1, and those with bars by a subscript 2.

51 Freeth 2014, Fig. S6.

52 Freeth 2014, Fig. S6 and tracings in Fig. 8.

53 Freeth 2014, Fig. S6.

19: The faint but complete alpha and small (uncertain) trace of pi survive in Fragment F only because the line was engraved in ecthesis; Crowther does not report them (though in his epigraphic notes he indicates "possible compatible traces of the left foot of alpha"), and the accompanying tracing shows them restored too far to the right.

22: Crowther assumes a *vacat* following δὲ, and comments that νότον in line 23 has to be understood adverbially as if it were νοτόνδε. There would have been enough room at the end of 22, however, for the expected preposition πρός as we restore the line.

29: In our transcription and translation, "(symbol)" stands for a symbol, very clear in the CT, consisting of an ascending and a descending stroke meeting at about half height, like a broad, low lambda, with the left ascending stroke continuing upwards and curving in an arc leftwards so that the top half of the symbol resembles that of a 2; following a suggestion of Gregg Schwendner,[54] we believe this was the numeral for 1000 (drawn as a notional alpha modified by a hooked stroke), though here functioning as a symbol supplementing the letters of the Greek alphabet. Crowther reports the entire line as (symbol)$\overline{\Pi}$Κ$\overline{\mathrm{Z}}$Φ. Freeth states (in agreement with our observations) that there is no trace of a bar over the zeta, so that the bar in the transcription is an editorial supplement.[55] Freeth does not mention any traces to the left of the barred pi. In fact, to the left of the pi, three further engraved letters are present, the first (approximately aligned with the beginning of line 28) apparently an apical letter, i.e. alpha, delta, or lambda, with no visible bar, the second a probable lambda, and the third a probable xi of the old form with a vertical crossing the middles of the three horizontal strokes (as also found in the Front Cover Inscription where xi is a numeral).

34: Crowther reports μικράν̣. The right portion of line 34 is very indistinct in the CT, and while the mu and alpha are sufficiently clear, the letters between them are a jumble of disconnected and blurry marks. A vertical to the immediate right of the mu is probable, but one cannot be sure of a single other stroke until one gets to the alpha. The structure of the inscription's paragraphs leads us to expect either μέσαι, "intermediate," or μικραί, "small." To our eyes, the hints offered by the CT slightly favor ικρ over εσ, but either would fit the space and could be reconciled with the traces. Of the final letter, all that can be made out with certainty is a slightly sloping vertical, serifed at the bottom and, apparently, at the top, though in Freeth's tracing this is interpreted as the top of the descending diagonal of nu. Very indistinct marks to the right of this vertical could be interpreted as parts of a second vertical, but this would be so close to the vertical of the following tau that the tau's horizontal

54 By comment posted at http://www.currentepigraphy.org/2009/03/18/peculiar-symbol-in-hellenistic-inscription/. In Greek papyri the numeral 1000 is sometimes written almost identically to the symbol in our inscription; see for example *PLond* 1.24 line 8 (Seider 1967, plate 9). We know of no other epigraphic example.

55 Freeth 2014, Fig. S6.

would have to be curtailed on its left side, as indeed it is shown in Freeth's tracing. We are confident that the letter is iota, followed by a properly formed tau of which the leftmost extremity is indistinct in the CT.

36: Crowther reports Ψ̣̄ following Ρ, and Freeth's tracing shows this letter about as far to the right of the rho as the other letters in this line are spaced apart. The supposed letter is described by Freeth as "hard to read, though definitely plausible".[56] In the CT we see a faint serifed, slightly sloping vertical, and possible but very slight traces of a V-shaped stroke crossing it.

56 Freeth 2014, Fig. S6.

4.5 Discussion of the Metonic and Games Dial Inscriptions

As noted above, the Metonic Dial scale's cells are inscribed with a repeating cycle of twelve month names (Table 4.1). Although very few of the cells are completely legible, the repetitions of month names guarantee that the foregoing spellings are all correct. Where necessary, the names were split into two or three lines within a cell according to proper division of syllables (note the division -ε|ύς reflecting a vestigial digamma).

Table 4.1: *The inscribed texts of the Metonic Dial*

(ἔτος) *n* Φοινικαῖος	Year *n* Phoinikaios
Κρανεῖος	Kraneios
Λανοτρόπιος	Lanotropios
Μαχανεύς	Machaneus
Δωδεκατεύς	Dodekateus
Εὔκλειος	Eukleios
Ἀρτεμίσιος	Artemisios
Ψυδρεύς	Psydreus
Γαμείλιος	Gameilios
Ἀγριάνιος	Agrianios
Πάναμος	Panamos
Ἀπελλαῖος	Apellaios

There were nineteen repetitions of the annual cycle covering the 235 cells of the scale, so that seven intercalary months must have been inserted somewhere in agreement with the requirements imposed by the Metonic cycle relation:

235 months = 19 calendar years = 19 x 12 months + 7 intercalary months

The legible cell sequences include a single instance of an intercalary month, a repeated Machaneus (the fourth month) in year 11.[57] It can be inferred from the surviving sequences that two intercalary months must have occurred within years 1-3 of the cycle, one within years 4-7, one within years 8-10, one within years 12-14, and one in years 16-19. This is not sufficient information to determine which years other than year 11 were intercalary. However, if a pattern distributing the intercalary years as evenly as possible as assumed, the sequence of ordinary (O) and intercalary (I) years must have been:

57 The cells in question had not been read in the 2008 edition, in which the calendar cycle was reconstructed *exempli gratia* on the assumption that the intercalated month was always the sixth, Eukleios.

I 0 0 I 0 0 I 0 0 I 0 I 0 0 I 0 0 I 0

This is the cyclic permutation of the sequence of optimally spread intercalations such that the beginning of year 1 falls earliest of the whole cycle relative to the solar year, e.g. relative to a solstice or equinox. We are confident that this is the correct sequence for the dial.

If the intercalary months were distributed with maximum evenness *in terms of months*, they would have occurred at intervals of 33 or 34 months, and this is contradicted by the absence of intercalations in cells 95-96 and 229-230. Hence either Machaneus was always the intercalary month, or more than one calendar month was occasionally duplicated but not following a pattern of even distribution. The data are consistent with repetitions of Machaneus in all intercalary years, but the confirmation of this hypothesis is not strong.[58]

The numerals in certain of the cells e1-e47 around the inner rim of the Metonic Dial indicate day numbers to be skipped over in the count from 1 through 30 in all months radially aligned with the inscribed cell. For example, the numeral 2 in cell e33 means that there is to be no day number 6 in Artemisios in year 3 (cell 33), in Dodekateus in year 7 (cell 80), in Lanotropios in year 11 (cell 127), and so forth. The scheme must have distributed 22 skipped days over 47 months in accordance with the Metonic relation:

235 months = 5 x 47 months = 6940 days = 5 x (47 x 30 days – 22) days

The legible inscriptions are consistent with the following scheme, which maximizes the evenness of distribution of skipped days (at intervals of 64 or 65 days) and of 29-day and 30-day months (Table 4.2).

Table 4.2: *Reconstructed scheme of skipped days of the Metonic Dial*

cells	*day*	*cells*	*day*
1, 48, 95, 142, 189	1	24, 71, 118, 165, 212	16
3, 50, 97, 144, 191	5	26, 73, 120, 167, 214	20
5, 52, 99, 146, 193	9	28, 75, 122, 169, 216	24
7, 54, 101, 148, 195	13	30, 77, 124, 171, 218	28
9, 56, 103, 150, 197	17	33, 80, 127, 174, 221	2
11, 58, 105, 152, 199	21	35, 82, 129, 176, 223	6
13, 60, 107, 154, 201	26	37, 84, 131, 178, 225	11
15, 62, 109, 156, 203	30	39, 86, 133, 180, 227	15
18, 65, 112, 159, 206	4	41, 88, 135, 182, 229	19
20, 67, 114, 161, 208	8	43, 90, 137, 184, 231	23
22, 69, 116, 163, 210	12	45, 92, 139, 186, 233	27

58 Anastasiou, Seiradakis, Carman, and Efstathiou 2014, Supplementary Appendix A.

Geminos, *Introduction to the Phenomena* chapter 8, describes a similar scheme in which days are to be skipped over (ἐξαιρέσιμοι) at intervals of 64 days throughout a Metonic or Callippic cycle. The word ἐξαιρέσιμος, which occurs also in the Mechanism's Back Cover Inscription (I 4),[59] had the technical sense of a day to be omitted from a calendar month to maintain correct astronomical alignment of the calendar, as is clear from Cicero, *In Verr.* 1.2.129:

"It is the custom of the Sicilians and the other Greeks, because they want their days and months to be in agreement with the behavior of the Sun and Moon, from time to time, if there was a discrepancy, to remove some single day or at most two days from a month, which they call *exairesimoi*; likewise from time to time they make a month longer by one day or two days".[60]

Cicero apparently describes a more haphazard practice than the schemes of Geminos and the Mechanism, which would never deduct more than two days from a month or add days to a month.[61]

The Back Cover Inscription (II 17-19) alludes to the 76-year Callippic period relation in terms that strongly suggest that a subsidiary dial, no longer extant, displayed the number of the current Metonic cycle within a 76-year cycle.[62] The Callippic period relation, being based on a quadrupling of the Metonic cycle, does not alter the ratio of months to years or require any change to the distribution of intercalary months, but it does change the ratio of days to months and years:

76 years = 940 months = 27759 days = 4 x 6940 days – 1 day

Hence if the designer of the Mechanism held the Callippic period relation to be accurate, it must have been intended that one further day was skipped over in every fourth Metonic cycle. The extant inscriptions give no hint of which day was to be omitted.

The identification of the specific calendar of the Metonic Dial inscriptions depends on matching its month names and their sequence with evidence for local calendars, chiefly attested

59 IAM 5.4.

60 "Est consuetudo Siculorum ceterorumque Graecorum, quod suos dies mensisque congruere uolunt cum solis lunaeque ratione, ut non numquam, si quid discrepet, eximant unum aliquem diem aut summum biduum ex mense, quos illi exaeresimos dies nominant; item non numquam uno die longiorem mensem faciunt aut biduo".

61 The only other instance of ἐξαιρέσιμος in this calendrical sense is pseudo-Aristotle, *Economics* 1351b15, recounting an anecdotal instance of a frugal general deducting a portion of soldiers' pay proportional to the number of skipped calendar days.

62 IAM 5.4.

in inscriptions. Inscriptional evidence from two geographical regions shows a significantly high rate of matching with the Mechanism's months. On the one hand a set of Hellenistic inscriptions from Tauromenion in Sicily provides an almost complete set of the month names of the local calendar and their sequence, which was as follows, starting with the month that began the year at Tauromenion (Table 4.3)[63]

Table 4.3: *The calendar of Tauromenion*

Ἀρτεμίτιος[64]	*Artemitios*
Διονύσιος	Dionysios
Ἑλώρειος[65]	Heloreios
Δαμάτριος	Damatrios
Πάναμος	*Panamos*
Ἀπελλαῖος[66]	*Apellaios*
Ἰτώνιος	Itonios
Καρνεῖος	*Karneios*
Λανοτρόπιος[67]	*Lanotropios*
Ἀπολλώνιος	Apollonios
Δυωδεκατεύς	*Dyodekateus*
Εὔκλειος	*Eukleios*

The seven italicized month names are in exact or near-exact agreement with the corresponding ones of the Mechanism's calendar, if we align the first month of the Mechanism's year, Phoinikaios, with the seventh of the Tauromenian calendar, Itonios. Hence it appears that both calendars descended from a common ancestor, but that at least one of them had undergone a process of substitution of new names for some of the months.

On the other hand, inscriptions from several localities in northwest Greece attest to month names that exactly or nearly match those of the Mechanism, though these give little hard evidence for the order of the months. The places in question were either colonies of Corinth in Epirus or members of the Epirotic League, and it appears highly probable that their calen-

63 For Artemitios as the first month of the Tauromenian year, see Battistoni 2011, 183.

64 The termination -ίτιος, lost from the Tauromenian inscriptional evidence, can be restored from parallels in related Sicilian calendars (Iversen 2015).

65 For this reading see Iversen 2015.

66 In IG XIV 429 we have an instance of Ἀπελλαῖος δεύτερος, i.e. an intercalary Apellaios following the normal one.

67 Battistoni 2011, 182 shows that the end of this name should probably be restored in agreement with the Mechanism's spelling.

dars were variants of the calendar of Corinth, for which unfortunately the direct evidence is slender. By 2007 Pierre Cabanes had identified the thirteen month names as belonging to the putative calendar of Corinth as attested in Epirus (Table 4.4).[68]

Table 4.4: *Month names identified by Cabanes as belonging to the calendar of Corinth, listed in his conjectural sequence*

Ἀρτεμίσιος/Ἀρτεμίτιος	*Artemisios/Artemitios*
Ψυδρεύς	*Psydreus*
Ἀγριάνιος	*Agrianios*
Φοινικαῖος	*Phoinikaios*
Ἁλιοτρόπιος	Haliotropios
Δάτυιος	Datyios
Κρανεῖος	*Kraneios*
Πάναμος	*Panamos*
Ἀπελλαῖος	*Apellaios*
Γαμίλιος	*Gamilios*
Μαχανεύς	*Machaneus*
Δευδεκατεύς	*Deudekateus*
Εὔκλειος	*Eukleios*

The degree of coincidence between the calendar in Epirus and the Mechanism's calendar is in fact still greater than appears from the ten matching names italicized in the above list. Datyios, attested in a single inscription from Dodona, probably does not belong to this calendar, and in fact may not even be a month name.[69] Eliminating Datyios makes room in the expected set of twelve month names for Deudekateus (also attested as Δυωδέκατος, Dyodekatos), which Cabanes supposed to be a name specifically for an intercalated month inserted in the twelfth place in an intercalary year; moreover, one inscription, IG IX,1 694, implies as a sequence of consecutive months Machaneus, Dyodekatos, Eukleios, Artemitios in agreement with the Mechanism's order. "Haliotropios," which supposedly signifies a month approximately coinciding with a solstice, turns out to be an editorial phantom misread or conjectured in inscriptions that variously appear to have had either Ἀλοτρόπιος, Alotropios, or Λανοτρόπιος, Lanotropios, the month name attested on the Mechanism and in Tauromenion.[70]

68 Cabanes 2007. A few inscriptions are dated with a month simply named ἐμβόλιμος, "intercalary."

69 Iversen 2013a.

70 Iversen 2013a. We concur with Iversen's disagreement with Cabanes's more recent effort to differentiate the calendar of Corinth (for which he adheres to his previous reconstruction) from that of the Mechanism, Cabanes 2011.

In the 2008 edition of the Metonic Dial inscriptions, it was suggested that the partial match of the months at Tauromenion to those in Epirus could be explained through the fact that Tauromenion had been refounded by Syracuse in the early fourth century BC as a colony of mercenaries. The calendar of Syracuse, like that of its founder, Corinth, is extremely poorly documented, but the authors of the 2008 edition hypothesized that Syracuse had substantially the same calendar as Epirus, and that the substitution of several different month names had occurred in connection with the adoption of a variation of Syracuse's calendar at Tauromenion. However, Paul Iversen has demonstrated that at least one month in use in Syracuse was different from those attested in Epirus and on the Mechanism, and that it is far more probable that the calendar of Tauromenion is simply the calendar of Syracuse.[71] We conclude, in agreement with Iversen, that the calendar of the Mechanism was intended to be a version of the calendar of Corinth as it was practiced either at Corinth itself or in some locality of Epirus.

The Games Dial's four quadrants bear inscriptions both inside and outside the circular outline of the dial. Inside the quadrants, in counterclockwise order, are inscribed year numbers from 1 through 4. Outside each quadrant, two lines of inscription give the names of two athletic festivals. It is noteworthy that this dial, the only one on the Mechanism for which the prevailing sense of motion of the pointer going forward in time was counterclockwise, is also the only one whose dial inscriptions are oriented with the tops of the letters towards the center; that is, on all the dials, the direction in which the inscriptions would have been read indicated the "forward in time" direction.

The names of six competitions appear in these inscriptions. Four of them are those of the Panhellenic Games: the penteteric Olympics (in year 1) and Pythians (in year 3), and the trieteric Isthmians (in years 1 and 3) and Nemeans (in years 2 and 4).[72] The arrangement of these competitions shows that the years indicated by the dial were not those of the calendar of Olympia or of Athens according to which the standard chronological Olympiad cycle was reckoned. In the Olympiad cycle, the Nemean games, which took place in the summer, and the Isthmians, which took place in the following spring, were assigned to the same years, since the beginning of the calendar years of Olympia and Athens both fell in early summer. The years of the Games Dial must have begun at some other time of year. It seems probable that they were intended to be the same as the years of the Metonic Dial, though for mechanical reasons what the Games Dial actually displayed were solar years of uniform length

71 Iversen 2013a. Full documentation of Iversen's contributions to the understanding of the Mechanism's calendar and its relations to the various local calendars discussed here will appear in Iversen (forthcoming, a) and (forthcoming, b).

72 "Penteteric" competitions were held every four years, "trieteric" competitions every two years. The Greek terms literally mean "every five years" and "every three years," reflecting the ancient practice of inclusive counting.

rather than lunisolar calendar years which could be either twelve or thirteen months long. The lines demarcating the quadrants are inclined about 8° counterclockwise from horizontal and vertical. In the 2008 study it was conjectured that, when the Mechanism was set to a date coinciding with the beginning of the first year of its Callippic cycle, the pointers of the Metonic and Games Dials would have been parallel, pointing straight down.[73] (This could also have been true of the pointer of the presumed Callippic Dial.) If so, the division lines of the Games Dial would have been approximately aligned with the latest possible beginnings of the Metonic Dial's calendar years. Iversen has persuasively argued that the Corinthian year began in the late summer, and conjectured that the division lines were intended to mark an astral phenomenon that was used to regulate the calendar on the assumption that it always fell within Phoinikaios; this event would most probably have been either the autumnal equinox or the morning rising of Arcturus.[74]

The second competition named in the Dial inscription for year 2 is the Naa, which took place at Dodona. An inscription from Dodona gives Apellaios as the month in which the Naa were held.[75] Year 4 too has a second competition whose name was not read in the 2008 edition but has since been identified with strong probability as the Halieia of Rhodes.[76] The order in which the two competitions are listed for each year of the cycle could reflect the order in which they were actually held in those years (assuming that the Halieia followed the Nemeans) or simply that the designer chose to list the trieteric games before the penteteric ones.

73 Freeth, Jones, Steele & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 21.

74 Iversen (forthcoming a).

75 Cabanes 1976, 586, text 71, reprinted by Cabanes 1988, 58. The festival is also sometimes written Νάϊα, but Νᾶα is the form found in local inscriptions.

76 Iversen 2013b and (forthcoming b), and cf. Iversen 2011 and 2013; Zafeiropoulou 2012, 247.

4.6 The Saros

The foundation of the Mechanism's eclipse predictions is the Saros, a period comprising 223 synodic months while approximating integer numbers of four other periodicities that play a role in eclipse phenomena:[77]

223 synodic months ≈ 238.992 periods of lunar anomaly
≈ 241.999 periods of lunar latitude
≈ 18.030 periods of solar anomaly
≈ 18.029 tropical years
≈ 6585.322 days

Hence if two syzygies are separated by 223 synodic months, the interval between them in days is close to constant (because of the near integer numbers of lunar and solar anomalistic periods), and the Moon will return to approximately the same elongation from the same node, while also being at approximately the same distance from the Earth. If the earlier of the two syzygies had a lunar eclipse, these circumstances suffice to ensure that the later one will almost always have a lunar eclipse of roughly the same duration, magnitude, and directions of obscuration as reckoned with respect to the ecliptic; the directions as reckoned with respect to the celestial equator will also be preserved, though less accurately because of the comparatively large error of the Saros as a period of tropical years. For any terrestrial place of observation, the local times of the second eclipse's beginning, middle, and end will be roughly 8 equinoctial hours later than those of the first eclipse. Thus it is possible for both eclipses to fall within the nighttime and so to be in principle observable, but in many cases an observable eclipse will be followed after a Saros by an unobservable, diurnal one. A triple Saros, called an Exeligmos (ἐξελιγμός, "turn of a wheel," a name cited by Geminus 18 and Ptolemy, *Almagest* 4.2), will normally bring a recurrence of lunar eclipses having approximately the same characteristics and approximately the same local times, though the cumulative effect of the not-quite-integer numbers of the various periods in three successive Saros cycles will result in some degradation in the repetition of the characteristics.

During a Saros, the Sun passes each lunar node 19 times, so that there will be 38 conjunctions and 38 oppositions when the Moon is closer to a node than at the preceding and following syzygies of the same kind. A lunar eclipse can only occur at such an opposition, and—with exceptions observable only at extreme terrestrial latitudes—a solar eclipse can only occur at such a conjunction. These syzygies are thus known as lunar and solar eclipse possibilities ("EPs"). The 38 EPs of a single kind (lunar or solar) are spaced at intervals of six months, with five intervals of five months interspersed among them, so that a Saros

77 For a discussion of the Saros as an eclipse cycle, with particular bearing on Mesopotamian eclipse prediction, see Steele 2000a, esp. 422-424 and 431-432.

contains three series of eight EPs and two series of seven EPs separated by six month intervals, in a cyclic permutation of 8-7-8-7-8. These intervals reflect the fact that five and six synodic months are close to but respectively less than and greater than an integer and a half periods of latitude:

5 mean synodic months ≈ 5.43 periods of latitude
6 mean synodic months ≈ 6.51 periods of latitude

The EPs of each kind strictly alternate between the two nodes, with the signed lunar elongation from the nearer node increasing in a six-month interval and decreasing in a five-month interval. Since in the course of any of the groups of EPs at six-month intervals the Moon approaches the node from behind and then recedes from it in advance, lunar eclipses tend to have greater magnitudes around the middle of the series, and the EPs flanking the five-month intervals may not be accompanied by umbral lunar eclipses. Solar eclipses behave less regularly because of the parallactic component in the Moon's apparent latitude as observed from a particular locality, but the conditions for eclipses are also more favorable towards the middle of each group of solar EPs.

The 38 solar EPs occur half a month away from the 38 lunar EPs. Because of the phase difference of half a synodic month between conjunctions and oppositions, in a group of seven or eight lunar EPs separated by six-month intervals, the solar EPs will follow immediately after the lunar EPs for the first half of the group, and immediately precede them for the last half of the group. In other words, in a group of eight lunar EPs, the first four will be followed by their solar counterparts and the last four will be preceded; and in a group of seven lunar EPs, the first three will be followed and the last three preceded by solar EPs, while the middle one may go either way depending on the precise alignment of the group with the nodes. Thus the groups of seven or eight solar EPs at six-month intervals are symmetrically out of phase with the groups of lunar EPs, with the five-month intervals between solar EPs falling in the middle of the lunar EP groups.

Seven six-month intervals followed by a five-month interval amount to 47 months, a sort of "poor man's Saros" that returns the Moon to just over the same elongation from the same node though not to the same stage in the lunar and solar anomalistic periods:

47 mean synodic months ≈ 51.004 periods of latitude

Thus lunar eclipses occurring at the *n*th EP in an eight-EP group and in the following group will be similar in their characteristics, though not as similar as lunar eclipses separated by a Saros. On the other hand, six six-month intervals followed by a five-month interval, amounting to 41 months, bring the Moon to just short of the same elongation from the opposite node:

41 mean synodic months ≈ 44.493 periods of latitude

Thus lunar eclipses occurring in the *n*th EP of a seven-EP group and in the following group will have similar magnitudes and durations, but the directions of obscuration are not preserved: if the Moon is obscured from its north side in one eclipse, it will be obscured from the south side in the other, and *vice versa*.

As we have already remarked, solar eclipses are highly contingent on the effects of parallax because the conditions for a solar eclipse depend on the apparent position of the Moon as seen from a point on the Earth's surface, and this can differ from the position as seen (notionally) from the Earth's center by an amount on the order of a degree, i.e. twice the Sun's apparent diameter. Both the magnitude and the timing of a solar eclipse are extremely sensitive to differences in parallax such as arise from the imprecisions of the Saros period relation. Consequently, the pattern of solar eclipses observable in a particular locality during one Saros will not be repeated in subsequent Saros cycles.[78] The Saros only allows one to predict which conjunctions are solar EPs, which even when diurnal may or may not be accompanied by observable eclipses, and to predict the approximate time of true conjunction, which might be taken as a very crude approximation of the time of mid-eclipse if an eclipse occurs.

78 An important difference between the treatment of solar eclipse prediction in ancient and modern astronomy is that, instead of investigating the path travelled by the shadow on the Earth's surface, ancient predictive methods sought to forecast the circumstances of the eclipse as observed from a specific locality.

4.7 The eclipse glyphs and their distribution

In the Antikythera Mechanism, eclipses were not displayed or predicted through a mechanical modelling of the relative configurations of the Earth, Moon, and Sun, comparable to the visual display of lunar phases by means of a rotating black-and-white ball on its front face.[79] Rather, eclipses were predicted schematically, by means of a dial representing an ostensibly repeating Saros cycle of EPs, which was established somehow prior to the construction of the Mechanism.[80] In this respect they were treated in the same way as the dates of first and last visibility of fixed stars: the conditions of stellar visibility were not mechanically modelled, but an annually repeating cycle of the phenomena, derived from observations or from a model of stellar visibility, was represented on the front Zodiac Dial.[81]

Roughly a third of the Saros Dial is preserved in Fragments A, E, and F. Its unusual spiral structure was essentially the same as that of the Metonic Dial situated directly above it;[82] in both cases the object appears to have been to enable a clear display of the current stage of a cycle lasting more than two hundred months, allowing sufficient space for each month on the dial's scale to inscribe a short text. As we have seen, the Saros Dial had a spiral slot of four turns perforating the Back Plate. A revolving pointer-follower tracked this groove clockwise from beginning (inside) to end (outside) as the Mechanism's input drive was cranked forward a number of turns corresponding to 223 synodic months as displayed, for example, by the motions of the solar and lunar pointers on the Zodiac Dial.[83] The spiral scale running along the outside of the groove was divided into 223 divisions or "cells" standing for the 223 months of the Saros. The months were evidently considered to begin with the first visibility of the new Moon, so that opposition would correspond to a position of the pointer close to the middle of a cell, and conjunction to a position close to its end.

Cells corresponding to months containing either a solar EP or a lunar EP or both were inscribed with a highly abbreviated text or "glyph"; the other cells were left vacant.[84] All 38 lunar EPs appear to have been inscribed, whereas some of the solar EPs were omitted.

79 For the Moon phase display see Wright 2006.

80 Freeth et al. 2006, 589.

81 Price 1974, 18; IAM 3.

82 The spiral structure of the back dials was deduced by Wright 2005.

83 Freeth et al. 2006, 589 with Fig. 3.

84 Our discussion of the distribution and contents of the glyphs follows Freeth et al. 2006, 589 (with Fig. 4) and Supplementary Information 5 and Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 24-41.

The following are examples of the three kinds of glyph that a cell could contain:

lunar EP	*solar EP*	*lunar and solar EPs*
Σ Μ/Η	Η	Σ ϕ Θ
ϕ Η	ϕ ς	Η ϕ Θ
Ε Ζ	$\overline{\text{Ρ}}$	

In the lunar EP glyph, the initial sigma identifies the EP as lunar (Σελήνη, "Moon," or perhaps σεληνιακή, "lunar"). The eta-mu monogram indicates a diurnal EP (ἡμέρας, "of day"); in the case of a nocturnal one (the "normal" situation for a lunar eclipse) it would be simply omitted.[85] The omega-rho monogram stands for ὥρᾳ, "at hour",[86] and the eta is the numeral 8, for the eighth hour. Lastly, epsilon is an index letter labelling the inscribed cell. The solar EP glyph begins with eta (Ἥλιος, "Sun," or ἡλιακή, "solar"), then the hour monogram and the numeral 6 (digamma), for the sixth hour. In this instance the EP is diurnal, the "normal" situation for a solar eclipse; if it was nocturnal, the hour monogram would be preceded by a nu-upsilon monogram (νυκτός, "of night"). Zeta is the index letter. The third example of a glyph contains a lunar EP (ninth hour of night) followed by a solar EP (ninth hour of day), and the index letter rho with a bar over it.

Every cell containing an EP or EPs had an index letter, and as the third example shows, a cell bore only a single index letter even if it contained two EPs. This will be an important consideration when we come to investigate the structure of the text to which the index letters refer, since it implies that the text must have been arranged in such a way that no ambiguity arose about whether the indexed text referred to a lunar or a solar EP. The inscribed cells were indexed in alphabetic order, running twice through the complete 24-letter standard Greek alphabet, and apparently through two or three further letters or symbols, making probably 50 or 51 indexed glyphs in all. The index letters of the second alphabet were distinguished from those of the first by bearing a horizontal stroke above the letter.[87]

85 Similar abbreviations by suspension of ἡμέρας and νυκτὸς in seasonal hour indications occur in astronomical papyri of the Roman period, e.g. the ephemeris *POxy astron.* 4179 from A.D. 348, for which see Jones 1999, 2.188-191.

86 This symbol is common in papyrus horoscopes and other astronomical papyri from the 2nd century AD onwards, e.g. *PFouad* 6, a horoscope for someone born in AD 125 (Neugebauer & van Hoesen 1959, 38-39). The earliest instance known to us, other than those on the Saros Dial, is a birthdate in AD 88 inscribed in horoscopic format, from Tremithos, Cyprus (Mitford 1961, 118-119).

87 Contrary to Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended 2012) 28, we are now convinced that the entire second alphabet was marked with bars above the letters (though some cannot now be discerned), as reported in Steele 2011, 464.

Since the 2008 publication of the glyphs detectable through surface imaging and CT in the surviving parts of the Saros Dial scale, two further glyphs have been detected. One occupies cell 8, which was reliably predicted to contain either a lunar or a lunar plus solar glyph, and unfortunately the glyph is not legible enough to determine which kind it was with certainty. The other is in cell 61, where a lunar glyph was predicted. Hence no further information has been obtained about the complete scheme of glyphs. In the 2008 publication, a model was also proposed for reconstructing the complete scheme in agreement with the attested glyphs, the principal challenge being to find a criterion for the omitted solar EPs that accounts for the attested glyphs, vacant cells, and index letters. This was not a unique solution,[88] and in the following we prefer to limit ourselves to certain assumptions about the scheme's structure that we consider to be very plausible:

(1) There was a complete set of lunar EPs in an 8-7-8-7-8 pattern.[89] Two alignments of the 8-7-8-7-8 pattern are possible consistent with the attested lunar glyphs. In one alignment the first EP of the first group of 8 was in cell 172, while in the other the first EP of the first group was in cell 37. The only difference between these distributions is that, starting with cell 172, we obtain a lunar EP in cell 214, but if we start with cell 37, the EP moves to cell 213. (The 2008 reconstruction started with cell 172.)

(2) The solar EPs were an incomplete but nearly complete subset of an 8-7-8-7-8 pattern.[90]

88 In Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended 2012) 32 it was asserted that only one alignment of the 8-7-8-7-8 groups for the lunar EPs was consistent with the preserved readings. We are grateful to Christián Carman for pointing out to us that a second solution is possible.

89 Every surviving cell that ought to contain a lunar EP if the set was complete does in fact contain one. The evidence would be consistent with having some lunar EPs (in lost cells) omitted, but some of these would have to be in the middle of the lunar EP groups, where eclipses of larger magnitudes are expected. We consider the omission of such EPs to be highly unlikely.

90 Seven 8-7-8-7-8 patterns are consistent with the attested solar glyphs, with the first set of 8 starting respectively at cell 60, 148, 13, 101, 189, 54, or 142, listed in increasing order of the total number of solar EPs that must be assumed skipped in cells preceding lunar EPs. (The existence of seven solutions was established by Christián Carman.) The first three of this list conform to the symmetry rule set out above if the lunar 8-7-8-7-8 began with cell 37, and the first two conform if the lunar pattern began with cell 172. Freeth 2014, Note S3, 2 proposes a model according to which the solar EPs are supposedly a subset of an 8-8-8-7-7 pattern, but the actual pattern resulting after the omissions (Freeth 2014, 5 Fig. 4) turns out to be almost identical to the reconstruction we present below in Table 4.6 which is based on an 8-7-8-7-8 sequence for both solar and lunar EPs, with the lunar sequence starting with cell 172. The only divergence is in cell 149, for which Freeth's re-

The distribution of the complete set of solar EPs, including the omitted ones, was out of phase with the lunar EPs in such a way that in a group of 8 lunar EPs at six-month intervals, the first four have solar EPs in the same cell and the last four have them in the preceding cell, while in a group of 7, the first three have solar EPs in the same cell and the last three have them in the preceding cell (leaving the middle EP undetermined by this symmetry rule).

(3) The omitted solar EPs were spread fairly evenly among the five groups composing the Saros.[91] This implies that the total number of glyphs was either 50 or 51, that is, there were either two or three additional letters or symbols following the two complete alphabets of index letters.

On this basis, we obtain the reconstruction presented in Table 4.5. In the table, an asterisk indicates an omitted solar EP or a vacant cell with no index letter, a slash means "or," and surviving glyphs or vacant cells are enclosed in boxes. Double horizontal strokes show the five-month intervals on the hypothesis that the first group of the 8-7-8-7-8 pattern begins with cell 172, and a broken horizontal stroke shows the slightly earlier placement of one five-month interval on the hypothesis that the first group begins with cell 37. The choice between these hypotheses only affects the glyphs and their index letter possibilities in cells 202-214; the glyphs and possible index letters resulting from starting in cell 37 are in parentheses.

construction posits a solar EP as well as the lunar EP. Neither this cell nor the solar eclipse paragraph of the Back Plate Inscription that would have referred to it if it contained a solar EP is extant. (Freeth's diagrams illustrating his reconstruction of the Saros Dial, e.g. p. 5, Fig. 4, also show the non-extant cell 143 as containing both a lunar and solar EP, but this appears to be an oversight since his Fig. S9, representing the derivation of his scheme of EPs, indicates that a solar EP is excluded in this cell.)

91 We further believe that the omitted solar EPs were probably all either adjacent to one of the five-month gaps or one EP away from a five-month gap, since the EPs in the middles of the groups often do correspond to observable solar eclipses. We do not use this hypothesis in the following analysis; if it is correct, the 8-7-8-7-8 pattern of solar EPs must have started with cell 60 since otherwise the omitted EP in cell 113 would be the third in its group.

Table 4.5: *Provisional reconstruction of the glyph distribution of the Saros Dial*

Cell	*EP*	*index*
2	ΣΗ/Σ*	Α
8	ΣΗ/Σ*	Β
13	Η	Γ
14	Σ	Δ
19	*	*
20	Σ	Ε
25	Η	Ζ
26	Σ	Η
31	Η	Θ
32	Σ	Ι
37	ΣΗ/Σ*	Κ
43	ΣΗ/Σ*	Λ
49	ΣΗ/Σ*	Μ
55	ΣΗ/Σ*	Ν
60	Η/*	*/Ξ
61	Σ	Ξ/Ο
66	Η/*	*/Ο
67	Σ	Π
72	Η	Ρ
73	Σ	Σ
78	Η	Τ
79	Σ	Υ
84	ΣΗ/Σ*	Φ
90	ΣΗ/Σ*	Χ
96	ΣΗ/Σ*	Ψ
102	ΣΗ/Σ*	Ω
107	Η	$\overline{\mathrm{A}}$
108	Σ	$\overline{\mathrm{B}}$
113	*	*
114	Σ	$\overline{\Gamma}$
119	Η	$\overline{\Delta}$
120	Σ	$\overline{\mathrm{E}}$
125	ΣΗ	$\overline{\mathrm{Z}}$
131	ΣΗ	$\overline{\mathrm{H}}$
137	ΣΗ	$\overline{\Theta}$

Cell	*EP*	*index*
143	ΣΗ/Σ*	$\overline{\mathrm{I}}$
148	Η/*	*/$\overline{\mathrm{K}}$
149	Σ	$\overline{\mathrm{K}}$/$\overline{\Lambda}$
154	Η/*	*/$\overline{\Lambda}$/$\overline{\mathrm{M}}$
155	Σ	$\overline{\Lambda}$/$\overline{\mathrm{M}}$/$\overline{\mathrm{N}}$
160	Η/*	*/$\overline{\mathrm{M}}$/$\overline{\mathrm{N}}$
161	Σ	$\overline{\mathrm{N}}$/$\overline{\Xi}$
166	Η/*	*/$\overline{\Xi}$
167	Σ	$\overline{\mathrm{O}}$
172	ΣΗ	$\overline{\Pi}$
178	ΣΗ	$\overline{\mathrm{P}}$
184	ΣΗ	$\overline{\Sigma}$
190	Σ*	$\overline{\mathrm{T}}$
195	Η/*	*/$\overline{\Upsilon}$
196	Σ	$\overline{\Upsilon}$/$\overline{\Phi}$
201	Η/*	*/$\overline{\Phi}$/$\overline{\mathrm{X}}$
202	Σ	$\overline{\Phi}$/$\overline{\mathrm{X}}$/$\overline{\Psi}$ ($\overline{\mathrm{X}}$/$\overline{\Psi}$)
207	Η/*	*/$\overline{\mathrm{X}}$/$\overline{\Psi}$/$\overline{\Omega}$ (*/$\overline{\Psi}$/$\overline{\Omega}$)
208	Σ	$\overline{\Psi}$/$\overline{\Omega}$/symbol ($\overline{\Omega}$/symbol)
213	Η/*(ΣΗ)	*/$\overline{\Omega}$/symbol (symbol)
214	Σ (no glyph)	symbol (no glyph)
219	ΣΗ	symbol

4.8 The times in the glyphs

In the 2008 publication, the precise meaning of the times recorded in the glyphs as well as their method of computation remained unsolved problems. A reconsideration of the evidence, including revised readings of a few times in the glyphs, suggests that at least a partial solution is possible. In our efforts to analyse these times, as in our examination of the Back Plate Inscription later in this paper, we adopt the broad principle that the designers of the Mechanism possessed a level of understanding of the astronomy of the Sun and Moon such that a competent astronomer of the time, say Hipparchos, would not have rejected their *theoretical* treatment of eclipses as grossly incompetent, whatever imprecisions there may have been in the execution. The mechanism for lunar anomaly seems ample justification for this confidence.

The time statements in the glyphs represent an abbreviated form of the conventional Greek formula for a time expressed in seasonal hours of day or night, "at hour n of day/night", where n is always a whole number from 1 through 12. In principle, "hour n of day" means a time within the interval between $(n-1)D/12$ and $nD/12$ counted from the moment of sunrise, where D is the duration of day from sunrise to sunset expressed in any constant time units, since the duration of one seasonal hour of day is defined as $D/12$. "Hour n of night" has the corresponding meaning in terms of the duration of night from sunset to sunrise. Two considerations, however, make it very unlikely that the times in the glyphs have precisely this meaning.

First, the Saros period is in excess of a whole number of years by more than ten days. Because of this, the lengths of daytime and nighttime will be significantly different for the dates of two eclipse possibilities separated by a Saros. This means that the time units would not remain constant for any particular glyph.

Secondly, because the Saros was not close to a whole number of days long, a time correction would be needed when forecasting any time associated with an eclipse on the basis of an eclipse one Saros back. The assumed overrun was one-third of a day, so that a triple Saros, called an Exeligmos, would make a whole number of days. The numerals 8 and 16 inscribed in two of the three sectors of the Exeligmos Dial are the numbers of hours to be added to the times in the glyphs for the second and third Saros of each Exeligmos cycle.[92] Hence they must be understood as equinoctial hours if they are to be applicable day and night throughout the year. The glyph times are thus in all probability *idealized* seasonal hours, reckoned as if there was no annual variation in the lengths of day and night, and so counted in *equinoctial* hours from 6 A.M. and 6 P.M. This convention is exactly paralleled in Greek lunar tables and

92 Freeth, Jones, Steele, & Bitsakis 2008, 615, Fig. 2 caption.

astronomical ephemerides from Roman Egypt.[93]

The division lines of the Exeligmos Dial are aligned so that the division marking the beginning of the third Saros of the Exeligmos (16 hours correction) radiates approximately horizontally to the left of the dial's center, and thus the division marking the beginning of the first Saros (0 hours correction) is approximately 30° clockwise of pointing straight upwards. We will return to this nonintuitive alignment at the end of this section.

Since the times are expressed in a consistent manner throughout the dial, it is only reasonable to assume that they should refer to the same stage of an eclipse or eclipse possibility in all the statements, whether they refer to lunar or solar EPs. This consideration limits us to just one candidate, the moment of syzygy. In a complete set of 38 lunar EPs in a Saros, some of the EPs will necessarily not be accompanied by umbral eclipses, so it would not be meaningful to give, say, a time for the beginning of obscuration. In the case of solar EPs, the situation is more extreme: because of the effects of parallax, the Saros does not enable one to make forecasts of the times or durations or even of the mere occurrence of solar eclipses visible in one geographical region on the basis of past eclipses. Hence unless the Saros Dial reflects a level of ignorance of the nature and behavior of solar eclipses that we would be reluctant to impute to a competent Hellenistic astronomer, the only meaningful times that could be associated with solar EPs in a repeating Saros cycle are the moments of syzygy.

We thus have a strong expectation simply from their mode of expression and their presence on the Saros Dial that the glyph times represent moments of syzygy counted in equinoctial hours from 6 A.M. for "day" or 6 P.M. for "night." It is easily established that the time interval between any pair of these times is not consistently the number of intervening lunar months (always an integer or an integer plus a half) times the length of a mean synodic month, so that the times must be of *true* syzygy, taking some account of the varying apparent speeds of the Sun and Moon.

In the kinematic approach to astronomy embodied by Ptolemy's *Almagest*, the time of true syzygy must be computed by an iterative process, taking the mean syzygy as a first approximation and repeatedly adjusting the time by the computed elongation of the Moon from the Sun divided by the estimated speed of the Moon relative to the Sun. A surprisingly good approximation can be obtained more directly by modelling the difference between the time of true and mean syzygy as the sum of two periodically varying components, one having as its period the anomalistic month and the other the solar year. In the Babylonian System A and System B lunar theories, time of true syzygy is calculated by algorithms equivalent to this kind of model, employing arithmetical functions to represent the periodic lunar and solar components.

93 Jones 1997, 27-29; Jones 1999, 1.14-15, 1.180, 1.187, 1.205.

We can illustrate this using the 446 syzygies within an arbitrary Saros cycle computed by modern theory. In Fig. 4.6 we plot (hollow markers) the difference between the times of true and mean syzygy (modulo 12 hours to simulate a situation in which times but not dates are given) against the stage of the anomalistic month. Obviously the predominant component of the time difference is a sinusoidally varying element dependent on lunar anomaly and having an amplitude of roughly 10 hours, while the values spread within a range of about ±5 hours of this component. The gray curve models this component as a scaled sine function with amplitude 9.7 hours.

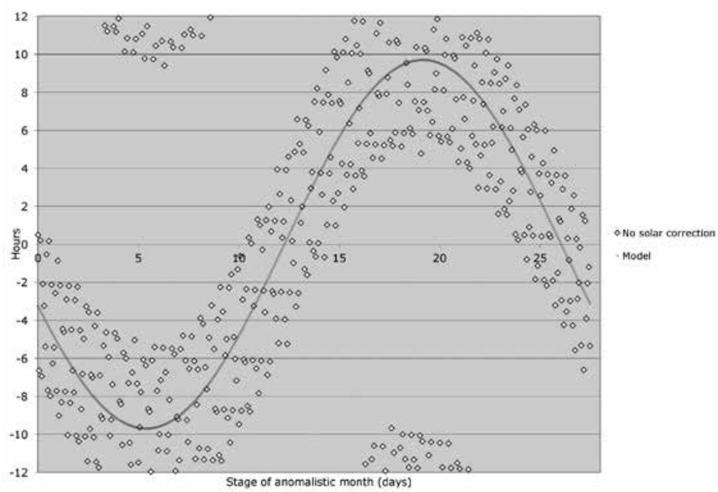

Figure 4.6: *Time of true syzygy minus time of mean syzygy plotted against stage of the anomalistic month, for syzygies of one Saros cycle computed by modern theory*

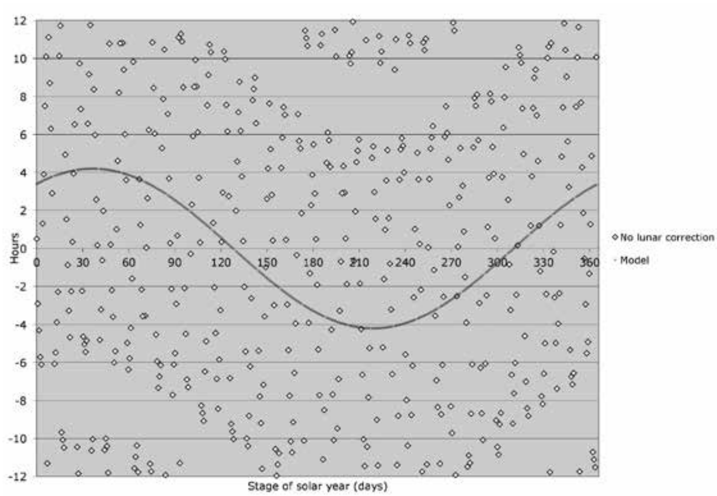

Figure 4.7: *Time of true syzygy minus time of mean syzygy plotted against stage of the solar year, for syzygies of one Saros cycle computed by modern theory*

In Fig. 4.7 we plot the same time differences (hollow markers) against the stage of the solar year, revealing that the values spread within a ±10 hour range around a component dependent on solar anomaly and with amplitude about 4 hours. If we correct the time difference by our sine-function model for the lunar component (Fig. 4.8), the residues (solid markers) cluster within roughly ±1 hour of a scaled sine function (gray line) having amplitude 4.2 hours. The solid markers in Fig. 4.9 similarly show how the data plotted in Fig. 4.6 are affected by correcting the time differences by the model for the solar component.

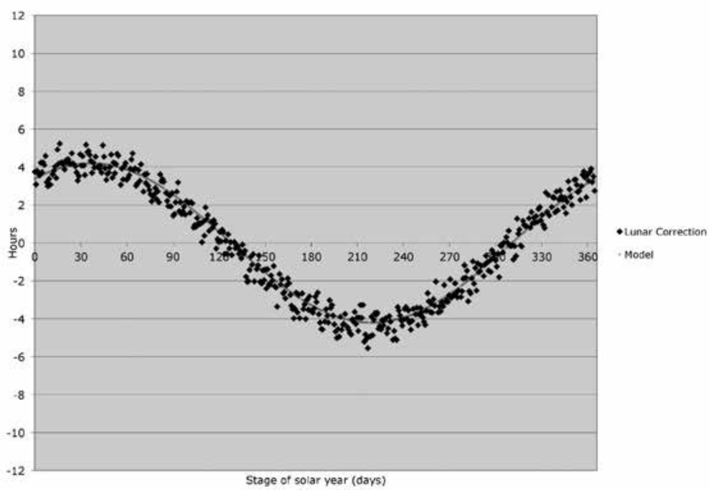

Figure 4.8: *Data from Figure 4.7 corrected by the sinusoidal lunar model of Figure 4.6*

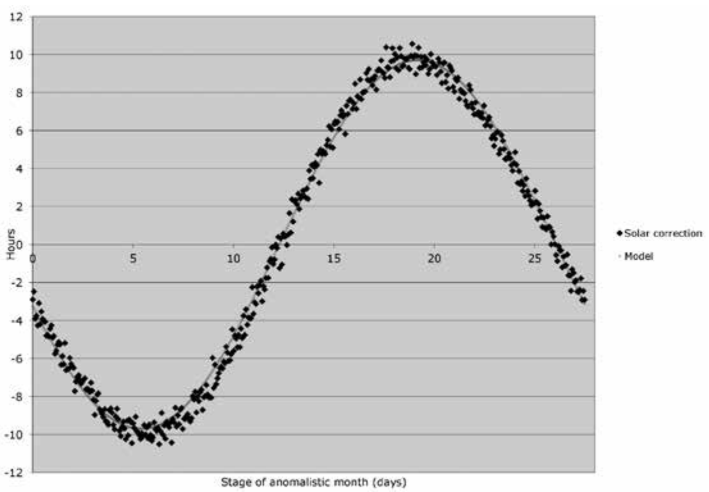

Figure 4.9: *Data from Figure 4.6 corrected by the sinusoidal solar model of Figure 4.7*

We now turn to the 22 reasonably secure times from the glyphs.[94] Since we do not have complete dates, but only times of day or night, we must estimate the alignment of the times relative to the times of mean syzygy. We have done this by assigning an arbitrary time of mean syzygy to any one of the syzygies, which determines the times of all the remaining mean syzygies in the Saros cycle, and adjusting the chosen time to see if a more or less symmetrical pattern of time differences can be obtained that could make sense as a sinusoidally varying lunar component blurred by a smaller solar component or other elements. We obtained the best results by assigning to the opposition of cell 1 a mean time of syzygy at 3 P.M.

Fig. 4.10 shows the differences between the times in the glyphs and our estimated times of mean syzygy plotted against the stage of the anomalistic month, where we have arbitrarily set the opposition of cell 1's month as day 0. Seventeen of the data points conform reasonably well, say within ±5 hours, to a sinusoidal model of appropriate amplitude, while five (corresponding to the lunar EPs of cells 125, 172, and 184 and the solar EPs of cells 13 and 119) do not. We believe that this is satisfactory confirmation that we are dealing with times of true syzygy computed by a method reflecting the influence of lunar anomaly, though a rate of one grossly discrepant value in five is unsettling.

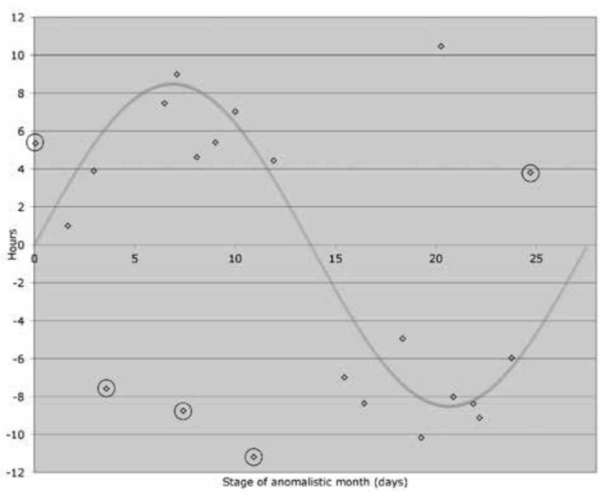

Figure 4.10: *Glyph time minus normed mean syzygy plotted against stage of the anomalistic month*

It deserves note that the lunar component appears to be near zero and increasing for the stage of the anomalistic month that we have defined as day 0. This implies that the Moon was close to its apogee at the opposition of cell 1. The Saros Dial is believed to have been calibrated to show the stage of the so-called Full-Moon Cycle, the beat period of the anom-

94 We assume that cell 20 did not indicate a diurnal hour.

alistic and synodic months, by means of four fiducial marks at 90° intervals immediately inside the dial and aligned so that the first of the marks was at cell 1; one of these marks survives.[95] Taken together, these considerations suggest that the Mechanism's Saros cycle may have been chosen so that cell 1's opposition was exactly at the lunar apogee. This would explain why the EPs do not start in cell 1.

We now plot in Fig. 4.11 the time differences corrected by our sinusoidal model against the stage of the solar year. The data points corresponding to the grossly discrepant time differences found in Fig. 4.9, circled in the present graph, should probably be disregarded. What remains shows less sign of a component dependent on solar anomaly than one might expect.

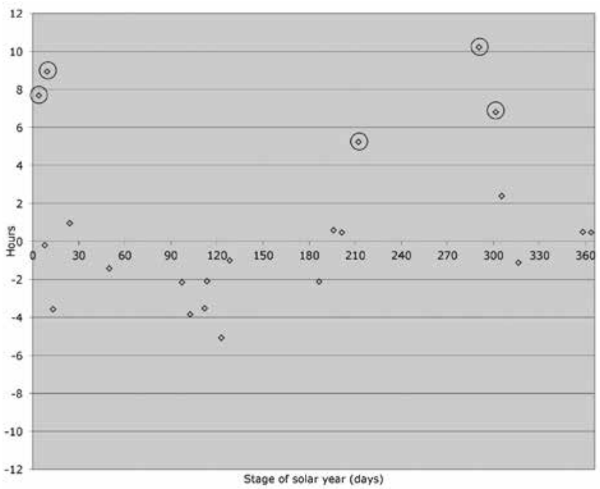

Figure 4.11: *Glyph time minus normed mean syzygy, corrected by lunar model from Fig. 4.10, plotted against stage of the solar year*

Our initial inference from the foregoing investigations was that the times in the glyphs were computed as times of true syzygy with a solar model that assumed either a small anomaly or none at all (i.e. effectively conjunctions and oppositions of the true Moon with the mean Sun) and that the calculations were comparatively sloppy to account for the remaining noise after the sinusoidal lunar correction was applied. However, in 2013 Christián Carman and James Evans, with whom we had shared our provisional conclusions, demonstrated that the glyph times could be successfully approximated, with significantly smaller errors than we found, by combining an optimized lunar model based on the assumption that lunar velocity behaves as a Babylonian-style linear zigzag function with an optimized solar model based

95 Freeth, Jones, Steele, and Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 39-40.

on the assumption that solar equation behaves as a linear zigzag function.[96]

Without recapitulating their more sophisticated analysis, we can confirm their deduction of a solar anomaly component. In Fig. 4.12 we reproduce the data of Fig. 4.11 together with a hypothetical sinusoidal solar component with amplitude ±3 hours, normed so that cell 1's opposition coincides with solar apogee, which appears to fit the data from the glyphs, aside from the outliers already identified, reasonably well. Fig. 4.13 shows the original data from Fig. 4.10 corrected by subtracting the sinusoidal solar component, plotted against the stage of the anomalistic month. The improvement of the fit to the hypothetical lunar component is obvious.

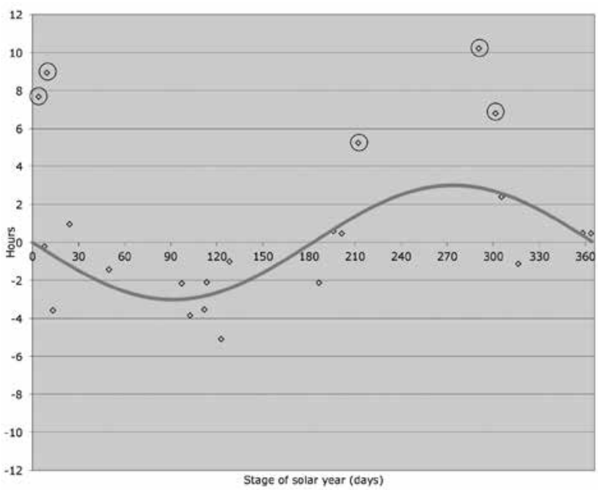

Figure 4.12: *Data from Figure 4.11 compared with a hypothetical sinusoidal solar component*

We conclude, then, that the times in the glyphs were calculated as times of true syzygy according to solar and lunar models that both involved anomaly. Carman, Evans, and Freeth suggest that these models were based on arithmetical functions rather than a trigonometrical representation of geometrical models.[97] The cycle of predictions on the Saros Dial was apparently normed such that at the opposition of its first month (cell 1) the Moon was assumed to be at its apogee.

96 Carman & Evans 2013; the research was subsequently published as Carman & Evans 2014. Freeth 2014, Note S4 similarly models the glyph times using Babylonian-style arithmetical functions, representing the time from one syzygy to the next as the sum of a zigzag function for the lunar component plus a zigzag function for the solar component, which is closer to the methods known from Babylonian astronomy.

97 We abstain here from appraising the merits of the specific models proposed in Carman & Evans 2014 and in Freeth 2014.

Carman and Evans have systematically deduced that this opposition was probably meant to be that of May 12, 205 BC, so that the epoch of the Saros Dial would have been the New Moon of April 29, 205 BC.[98] We note, that if we accept both the April 29, 205 BC epoch date and Iversen's conjecture that the epoch of the Mechanism's Callippic cycles was four lunar months later, August 23, 205 BC,[99] then when the Mechanism was set to the latter date, not only would the pointers of the calendrical upper dials have been parallel, pointing straight down, but also the pointers of the Saros and Exeligmos Dials would have been very nearly parallel, pointing about 30° clockwise of straight up. This seems likely to be the explanation why the Exeligmos Dial was normed so that its pointer had this orientation at the beginning of each cycle. It would be beyond the scope of the present paper to discuss at greater length the question of how these epoch dates relate to that of the construction of the Mechanism, beyond the obvious point that at a minimum it provides us with a *terminus post quem*.

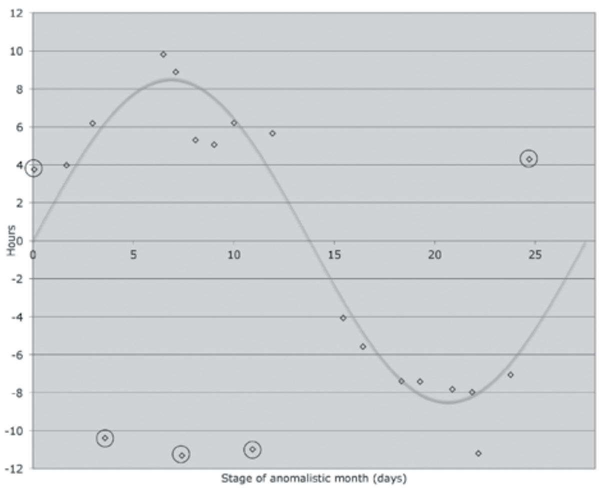

Figure 4.13: *Data from Figure 4.10 corrected by subtracting the solar component of Figure 4.12*

98 Freeth 2014, 11 and Note S5 arrives at the identical epoch date by methods that he asserts (Note S5, 2) are "entirely different" from those of Carman and Evans (citing Carman & Evans 2013), though many of the same considerations are taken into account.

99 Iversen (forthcoming, a).

4.9 Overview of the Back Plate Inscription

The Back Plate Inscription consists of a series of rigidly patterned sections or paragraphs, each comprising three parts. The first part is a sentence asserting that some unstated plural subject starts (present tense) from a certain direction, "veers about" —in one instance, "veers about towards" a certain direction— and "ends up towards" a certain direction. The terms used to specify directions are the names of winds such as *boreas* and *apêliôtês*, which were conventionally employed to designate directions on the horizon according to various "windrose" schemes. This sentence about directions is followed by a stand-alone adjective (nominative plural, feminine).[100] The last part is a statement that "the color is" a certain hue. Following each paragraph is a single line consisting of a series of alphabetic letters (and at least one nonalphabetic symbol) that do not spell out recognizable words, with horizontal bars over some of the letters.

These letters with and without bars immediately suggest a connection with the index letters of the Saros Dial. To understand the function of the index letters, it is helpful to consider the other place on the Mechanism where such index letters are found.[101] The Zodiac Dial at the center of the front face had a graduated scale representing the twelve zodiacal signs and 360 degrees of the ecliptic. Certain degree marks are labelled with letters, running in alphabetic order. These letters associated their degrees with letter-indexed lines in an inscription elsewhere on the front face listing annually repeating astronomical phenomena, namely the first and last morning and evening visibilities of stars and constellations, solstices and equinoxes, and the Sun's entry into zodiacal signs. When a revolving pointer representing the Sun's longitude on the central dial indicated a labelled degree, the corresponding phenomenon in the indexed inscription was predicted. The index letters of the Saros Dial surely had an analogous function, linking the glyphs to a text, inscribed somewhere else on the Mechanism, that gave fuller information about the predicted eclipses. We may identify the Back Plate Inscription as this text, and the lines of letters alternating with the paragraphs as the index letters that link the preceding paragraphs to the corresponding glyphs. Thus it appears that the predictions in a single paragraph were applicable to several eclipses in the Saros cycle.

Taking Fragment A (some of whose lines are supplemented by Fragment E) and Fragment F together, we appear to have a continuous run of five paragraphs and their associated index letter lines, concluding near the bottom of the Back Plate. We can infer that the index lines belong with the paragraphs that precede them because the final index line (36) is close enough to the lower edge of the plate so that there would be no room for further text. The

100 In one instance, lines 14-15, we appear to have an accusative singular feminine adjective; we think this is a textual error.

101 Price 1974, 18; IAM 3. For the principle of alphabetical indexing, and parallels on some Greek sundials, see Steele 2011, 461-465.

smaller triangular spaces at the four corners of the Back Plate had room for just two paragraphs each, while the two larger spaces at the middles of the plate's right and left sides had room for four. Thus the inscription potentially comprised sixteen paragraphs. One might guess provisionally that paragraphs referring to lunar EPs ran down one side of the plate, and paragraphs referring to solar EPs down the other;[102] such an arrangement would explain why nothing in the surviving part of the inscription seems to identify which kind of eclipses the paragraphs relate to, and why a single index letter was considered as an unambiguous reference for both a lunar and a solar EP when both fell within the same month. We shall see later on, however, that the solar EP paragraphs would not have required all the space available along the right side of the plate.

102 Freeth 2014, 7-8, proposes an arrangement with the lunar paragraphs on the two sides of the Metonic Dial and the solar ones on the two sides of the Saros Dial. However, the first preserved paragraph straddles the line of division between the upper and lower halves of the Back Plate, so the arrangement we propose here appears preferable.

4.10 The groups of index letters[103]

Three index lines are partly preserved on Fragment A, but because of surface damage many of the letters are uncertain. The two index lines in Fragment F, however, are largely legible, and it is with these that we begin our attempt to recover the principle according to which the EPs were grouped. In line 29, we have the letters Λ, Κ, Ζ, and Φ with no visible bar over them, $\overline{\Pi}$ and (uncertainly) Ξ, and a symbol that resembles a notation for the numeral 1000 found in Greek papyri. In line 36, we have Τ and Θ with no visible bar, and $\overline{\mathrm{H}}$ and $\overline{\mathrm{P}}$ with bars. In comparing these letters with the reconstructed Saros Dial scheme (Table 4.5), we need to keep in mind that a bar over a letter may simply have been engraved too slightly to be detectable in the CT. Nevertheless we initially take the readings at face value.

Three securely read barred letters ($\overline{\mathrm{H}}$, $\overline{\Pi}$, $\overline{\mathrm{P}}$) are associated with cells that contained both lunar and solar glyphs. Of the securely read letters with no visible bar, two (Κ, Φ) are also associated with cells containing both lunar and solar glyphs; Λ has a cell that could have had both kinds or just lunar; but the other three (Ζ, Θ, Τ) are associated with cells containing only solar glyphs. It is unlikely that all three of these were really barred letters whose bars are escaping detection, so we can conclude that the part of the inscription that we possess was not entirely concerned with lunar EPs, whereas it may have been entirely concerned with solar EPs.

Now three letters in line 29, Κ, Φ, and $\overline{\Pi}$, turn out to be associated with cells 37, 84, and 172, which contain not only solar EPs but also the first lunar EPs of three of the five groups of seven or eight lunar EPs at six-month intervals. The remaining two of these lunar groups begin with cell 125, which is indexed with $\overline{\mathrm{Z}}$, and either cell 219 or cell 213, which was indexed with one of the undetermined additional letters or symbols that followed the second complete alphabet. When we further observe that a securely read, definitely unbarred Ζ has already appeared in line 18 of the inscription, the conclusion seems inescapable that the Ζ in line 29 was actually supposed to be barred —a scribal error seems likely here rather than a defect of the CT— while the special symbol was one of the additional notations following the complete alphabets. Thus all five cells containing the first lunar EPs of the 8-7-8-7-8 groups were indicated in line 29.

This is a very important result, because it implies that the elongation of the Moon from the node was in some way involved in the groupings of EPs in the inscription. If it is lunar EPs that these five letters in line 29 are referring to, then the Moon was near the maximum negative elongation from the node that is possible for an EP, whereas if the line refers to solar EPs,

103 Some findings in this section confirm conjectures explored, with generally inconclusive results, by T. Freeth in collaboration with some of the present authors (Steele, Jones, and Bitsakis) in 2009. See also Freeth 2014, Notes S2 and S3.

then the Moon had a very small elongation, in the immediate vicinity of the node; either way, we can speak of a comparatively narrow zone of nodal elongation that accounts for most, perhaps all, of the EPs in line 29. The EPs in this group were not, however, all at the same node, since the intervals between them form a cycle of 47-41-47-41-47 synodic months, and as we have seen, an interval of 41 months brings about a change of node.

Turning to the group of index letters in line 36, we observe that one pair among them, $\overline{\text{H}}$ and $\overline{\text{P}}$, designated a pair of cells (131 and 178) that contain both lunar and solar glyphs and that come immediately after cells 125 and 172 whose index letters are in line 29. The other pair, Θ and T, designated cells 31 and 78, which contain only solar glyphs and which, in the sequence of solar EPs, come immediately *before* cells 37 and 84 whose index letters are again in line 29. The fact that the two groups are related in this way leads us to two conclusions: first, that all the letters in both groups probably refer to the solar EPs in the corresponding cells, and secondly, that line 36's group contained solar EPs falling with two small zones of nodal elongation flanking the zone of nodal elongation associated with line 29.

To develop this idea, we calculated nodal elongations for all 38 solar EPs in the Saros cycle, neglecting the effects of solar and lunar anomaly, and hypothetically assigning to the EP of cell 125 a small positive nodal elongation so that the EPs are distributed according to the pattern derived above in which the first lunar EP of the 8-7-8-7-8 cycle is that of cell 172. Fig. 4.14 plots the recomputed nodal elongations, and shows by horizontal lines hypothetical boundaries for a 5° wide zone of nodal elongation (from –1° to +4°, between the solid lines) which takes in most of the identified EPs of line 29 and two 2.5° wide zones (from –3.5° to –1° and from +4° to +6.5°, between the broken and solid lines) which take in most of the EPs of line 36.[104] The graph shows that the EPs of both cells 213 and 219 fall within the central zone; one of these presumably was indexed with the special nonalphabetic symbol in line 29. On the other hand, it cannot be the case that the inscription's groups comprised *all* solar EPs falling within a particular zone as shown in this graph, since by that criterion cell 43's index letter (Λ) ought to be in line 36, rather than line 29.

104 In the graph, double letters AA, BB stand for additional symbols used after the completion of the second alphabetic sequence.

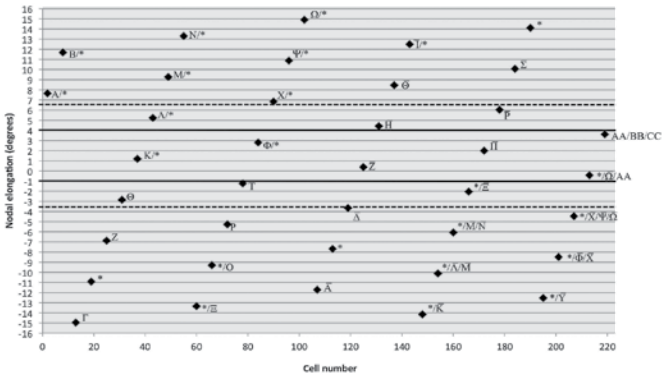

Figure 4.14: *Schematic calculation of nodal elongations of the solar EPs. Asterisks indicate definite or possible omission of a solar glyph according to the reconstructed glyph distribution*

Bringing line 18's index letters into consideration helps to bring out a pattern. This line begins with Ζ, a probable $\overline{\Theta}$, and Σ. Like the Ζ in line 29, the Σ in line 18 ought to have a bar though we cannot see it. For it cannot be an accident that we have the following pattern for sets of three consecutive cells:

line 18	*line 36*	*line 29*
Ζ (cell 25, solar)	Θ (cell 31, solar)	Κ (cell 37, solar)
$\overline{\Theta}$ (cell 137, lunar-solar)	$\overline{\mathrm{H}}$ (cell 131, lunar-solar)	$\overline{\mathrm{Z}}$ (cell 126, lunar-solar)
$\overline{\Sigma}$ (cell 184, lunar-solar)	$\overline{\mathrm{P}}$ (cell 178, lunar-solar)	$\overline{\Pi}$ (cell 172, lunar-solar)

It appears that, in the progression from the group of line 29 to that of line 36 and then to that of line 18, we are picking successively earlier solar EPs in some series, but successively later ones in others. Hence we may predict that line 18 ought also to contain the index letter Ρ (cell 72, preceding Τ in line 36), and this is consistent with the space for and doubtful traces of an indeterminate but narrow letter (thus likely Ι or Ρ) between Σ and the uncertain Χ.

Summing up, a partial condition for inclusion in a group appears to have been that the Moon's nodal elongation fell within one of two ranges of values symmetrically situated with respect to the range of line 29's group; three series of solar EPs use the ranges on one side of the "central" range, and two series use the ranges on the other side. However, our analysis has not revealed the rationale for the order in which the groups were presented in the inscription, or for the order of the index letters within each group. We can partially confirm the three groups that we have so far discussed as follows, with barring of some letters supplementing what is visible in the images:

(line 29) (symbol)-219 $\overline{\Pi}$-172 Κ-37 $\overline{\mathrm{Z}}$-125 Φ-84
(line 36) Τ-78 $\overline{\mathrm{H}}$-131 Θ-31 $\overline{\mathrm{P}}$-178
(line 18) Ζ-25 $\overline{\Theta}$-137 $\overline{\Sigma}$-184 Ρ-72

This is as far as we had succeeded in understanding the index letter groupings by 2012.

A significant advance has been made subsequently by Freeth, by demonstrating that nodal elongation is not the *immediate* criterion for inclusion in a group, but rather the lunar latitude, which, though functionally dependent on nodal elongation, depends for its sign on both the sign of the elongation and whether the nearby node is the ascending or descending node.[105] In addition to clarifying the principles of inclusion or exclusion of EPs in the groups of the inscription, this hypothesis also satisfactorily explains the order of the index letters in each group. In the following, we adopt this hypothesis in carrying forward our own line of analysis of the data. Our results confirm Freeth's proposal while also showing that his detailed reconstruction of the scheme of EP groupings and their rationale requires amendment.

The hypothetical zones of nodal elongation drawn in Fig. 4.13, which we chose so as to reproduce as well as possible the allotment of index letters in lines 29 and 36 of the inscription, are not symmetrical with respect to positive and negative elongation. Hence if we wish to preserve the grouping while replacing nodal elongation with lunar latitude as the measure, we have to introduce a small negative shift in the assumed elongations. Fig. 4.15 shows the lunar latitudes for the EPs, using elongations reduced by 1.5° from the values assumed in Fig. 4.13, an amount chosen by trial and error. We have drawn horizontal lines as before to demarcate zones (now of lunar latitude) grouping together the index letters in lines 9, 18, 29, and 36. The match of these zones to the evidence of the inscription is now excellent, both in terms of which index letters fall in each group and in terms of the order of the letters, which approximately corresponds to order of decreasing latitude.[106]

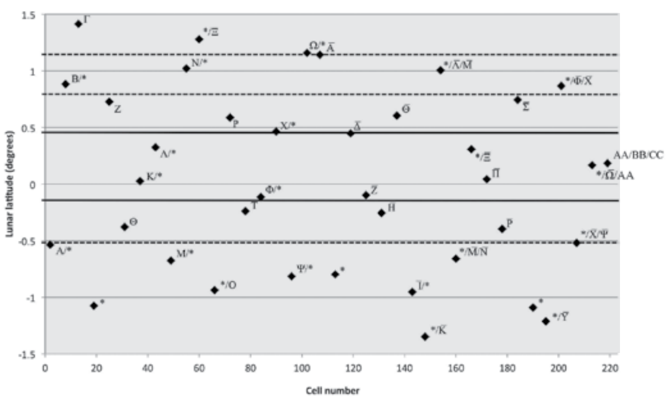

Figure 4.15: *Schematic calculation of lunar latitudes of the solar EPs. Asterisks indicate definite or possible omission of a solar glyph according to the reconstructed glyph distribution*

105 Freeth 2014, Notes S2 and S3.

106 Small discrepancies in the order of letters may be attributed to uncertainties about precisely how the nodal elongations and latitudes were computed.

Freeth noted that the inscription paragraphs to which lines 9, 18, 29, and 36 belong correspond to solar EPs for which the lunar latitude is respectively farther north, north, close to zero, and south. Not being aware of the first three index letters in line 29, however, he conjectured a paragraph with EPs with a range of northerly latitude intermediate between the ranges of lines 18 and 29, placing this in the lost lower left corner of the Back Plate. We can now see that the EPs indexed Λ (cell 43) and Ξ̅ (cell 166, restoring a bar over the letter) were part of the line 29 group, which must therefore have extended further north of the ecliptic than it did south. The first index letter of line 29 must have been Δ̅ (again, the bar cannot be seen in the CT), and this establishes an approximate upper bound for the line 29 group's latitudes since the EP labelled X (cell 90), which had close to the same latitude, is confirmed for the line 18 group.

Revising Freeth's reconstruction of the inscription, we propose that the solar EPs were all described in a series of five paragraphs running down the right side of the Back Plate, with the paragraphs as well as the individual EPs within each paragraph ordered from most northerly to most southerly lunar latitude. The paragraph of line 36 was the last one, and in fact all EPs below the southern boundary of line 36's zone in Fig. 4.14 could have had no solar glyph according to our reconstructed distribution. This confirms the hypothesis proposed in the 2008 publication that the omission of solar EPs from the full set of 38 was intended to reflect the effect of parallax, which for an observer in the northern hemisphere makes the Moon's apparent latitude more southerly than its true latitude (calculated as if seen from the center of the Earth).[107]

The exclusion of the EPs with lunar latitude more southerly than the boundary of line 36's zone means that there would have been just 27 solar EPs with glyphs. The complete set of paragraphs for the solar EPs clearly required less than half the available space around the dials on the Back Plate, so we raise the possibility that the paragraphs for the 38 lunar EPs were more detailed and took up all the spaces along the left side as well as the space in the top right corner.

We are now in a position to narrow down the possibilities for reconstructing the glyph distribution of the Saros Dial and the index lines of the Back Plate Inscription's solar paragraphs. We take as principles (1) that all solar EPs that fell within the five more northerly zones in Fig. 4.14 had solar glyphs indexing to the appropriate paragraphs of the inscription (this allows us some restorations and resolutions of unclear letters),**[108]** and (2) that all solar EPs

107 Freeth, Jones, Steele, & Bitsakis 2008, 616.

108 Lost index line corresponding to northernmost zone restored as Γ Ξ Ω. Line 9 restored as Α̅ Ν Λ̅ Β Φ̅. Line 18 restored as Ζ Θ̅ Σ̅ Ρ Χ (though Σ̅ should properly be in either first or second place). Line 29 restored as Δ̅ Λ Ξ̅ (symbol) Π̅ Κ Ζ̅ Φ. Line 36 requires no restorations: Τ Η̅ Θ Ρ̅ Ψ̅.

that fell in the southernmost zone did not have solar glyphs. The first of these principles gives us the following restorations of the index lines of the inscription:

4? Γ Ξ Ω
9 $\overline{\mathrm{A}}$ N $\overline{\Lambda}$ B $\overline{\Phi}$
18 Z $\overline{\Theta}$ $\overline{\Sigma}$ P X
29 $\overline{\Delta}$ Λ $\overline{\Xi}$ (symbol) $\overline{\Pi}$ K $\overline{\mathrm{Z}}$ Φ
36 T $\overline{\mathrm{H}}$ Θ $\overline{\mathrm{P}}$ $\overline{\Psi}$

The paragraph for the most northerly solar EPs ought to have been the one represented by the very damaged lines 1-4 if the solar paragraphs were all together and in appropriate order from north to south; that there *was* a paragraph for these EPs is certain since the extant solar glyph in cell 13 (Γ) belongs in it. We suggest that the clear but fragmentary trace of a single letter in line 4 was the right half of omega in its cursive (open-topped) form.[109] The barred sigma in line 18 should, as Freeth already noted, be the first index letter in the line; we agree with him that this is probably a copying error.[110]

The principles turn out to eliminate all uncertainties in the Saros Dial's glyph sequence except for whether the second last lunar EP was in cell 213 or 214 (Table 4.6). If the lunar 8-7-8-7-8 sequence began with cell 172, cell 213 was a solar-lunar glyph, cell 214 was vacant, and only cells 213 and 219 were indexed by nonalphabetic symbols; if the sequence began with cell 37, cell 213 was solar, 214 lunar, and the three cells 213, 214, and 219 had nonalphabetic symbols. Thirdly, according to our reconstruction both cells 213 and 219 ought to be referenced in line 29, one after the other in the list. Since there is only one nonalphabetic symbol in this line, we think it is possible that the same symbol served for both cells.

109 The cursive omega is not attested elsewhere in the Mechanism's inscriptions as a letter in its own right, but the symbol for ὥρα in the glyphs is based on this form.
110 Freeth 2014, Note S3, 3.

Table 4.6: *Revised glyph sequence reconstruction for the Saros Dial*

Cell	*EP*	*index*
2	Σ*	Α
8	ΣΗ	Β
13	Η	Γ
14	Σ	Δ
19	*	*
20	Σ	Ε
25	Η	Ζ
26	Σ	Η
31	Η	Θ
32	Σ	Ι
37	ΣΗ	Κ
43	ΣΗ	Λ
49	Σ*	Μ
55	ΣΗ	Ν
60	Η	Ξ
61	Σ	Ο
66	*	*
67	Σ	Π
72	Η	Ρ
73	Σ	Σ
78	Η	Τ
79	Σ	Υ
84	ΣΗ	Φ
90	ΣΗ	Χ
96	Σ*	Ψ
102	ΣΗ	Ω
107	Η	$\overline{\mathrm{A}}$
108	Σ	$\overline{\mathrm{B}}$
113	*	*
114	Σ	$\overline{\Gamma}$
119	Η	$\overline{\Delta}$
120	Σ	$\overline{\mathrm{E}}$
125	ΣΗ	$\overline{\mathrm{Z}}$
131	ΣΗ	$\overline{\mathrm{H}}$
137	ΣΗ	$\overline{\Theta}$
143	Σ*	$\overline{\mathrm{I}}$
148	*	*
149	Σ	$\overline{\mathrm{K}}$
154	Η	$\overline{\Lambda}$
155	Σ	$\overline{\mathrm{M}}$
160	*	*
161	Σ	$\overline{\mathrm{N}}$
166	Η	$\overline{\Xi}$
167	Σ	$\overline{\mathrm{O}}$
172	ΣΗ	$\overline{\Pi}$
178	ΣΗ	$\overline{\mathrm{P}}$
184	ΣΗ	$\overline{\Sigma}$
190	Σ*	$\overline{\mathrm{T}}$
195	*	*
196	Σ	$\overline{\Upsilon}$
201	Η	$\overline{\Phi}$
202	Σ	$\overline{\mathrm{X}}$
207	Η	$\overline{\Psi}$
208	Σ	$\overline{\Omega}$
213	Η (ΣΗ)	symbol
214	Σ	symbol
	(no glyph)	(no glyph)
219	ΣΗ	symbol

4.11 The direction statements

What would the information in the paragraphs have meant in relation to eclipses? To anyone familiar with the treatment of eclipses in ancient Near Eastern and Greco-Roman astronomy and astrology, the statements about directions will suggest two possible meanings: either the directions from which the lunar or solar disk appears to be obscured at the various stages of the eclipse, or the changing directions of actual winds blowing during the eclipse. The adjectives and adjectival phrases seem to be a qualitative indication of the eclipse magnitude. Lastly, the colors would be descriptive of the appearance of the lunar or solar disk during the eclipse. We will explore these interpretations at greater length below.

From a modern point of view, no natural connection is to be expected between the occurrence of an eclipse and the blowing of winds in a locality where it is observable, except for the marginally verified phenomenon of winds induced by total solar eclipses.[111] Nevertheless there was a strong tradition in Mesopotamian and Greek astronomy, astrology, and meteorology regarding "eclipse winds" as observable and significant phenomena. The tablets of lunar eclipse omens in the Babylonian series *Enūma Anu Enlil* (composed before the 7th century BC) contain many omen texts in which the directions from which the lunar disk is obscured at the beginning and end of the eclipse, or the direction of the wind blowing during the eclipse, or both are factors in the "if" clause of the omen.[112] Babylonian eclipse observations from the first millennium BC also regularly include reports of the directions of obscuration at the eclipse's beginning and end as well as the wind direction prevailing during the eclipse (occasionally it is noted that the wind direction was different at the beginning and end of the eclipse).[113] We have no evidence that Babylonian astronomers made predictions of directions of obscurations or wind directions during eclipses.[114]

The Greeks definitely believed that wind directions were to some degree predictable. Many of the annually recurring weather phenomena recorded in *parapêgmata* in relation to stellar first and last visibilities, solstices, and equinoxes were specific directional winds. Nor did this presumed annual cycle preclude other intermittent weather signs predicting winds; non-annual phenomena, both meteorological and astral, could also act as weather signs. Shooting stars, for example, were signs predicting winds blowing from the quarter to which they were seen

111 For the apparent reality of the solar "eclipse wind" see Gray & Harrison 2013.

112 Rochberg-Halton 1988, 51-55 and 57-60. Interestingly, the solar eclipse omens do not incorporate winds or directions of obscuration in their "if" clauses (Francesca Rochberg by personal communication).

113 Huber & De Meis 2004; Gautschy 2012.

114 Cuneiform texts survive containing schemes for predicting weather through correlation with planetary periods, but they make no reference to specific wind directions or eclipses; see Hunger 1976.

heading;[115] if the northern or southern stars of Cancer called *Aselli* (ὄνοι, γ and δ Cnc) become invisible, it is a sign respectively for the north or south wind;[116] ebb tide signified a north wind and flood tide a south wind;[117] frequent flashes of lightning in one part of the sky signified wind from that direction.[118] Ptolemy attributes to both the planets and the zodiacal signs a power to set particular winds in motion.[119] The unknown author of the book on weather signs conventionally attributed to Theophrastos mentions that weather changes are correlated with the Moon's phases,[120] and that a gap observed in a halo around the Moon or Sun indicated the onset of a wind from the quarter corresponding to the orientation of the gap.[121]

A connection between eclipses and winds is mentioned by Aristotle, *Meteorologica* 367b25-32, where it is asserted that an onset of wind occurs *before* a lunar eclipse (at sunset for a midnight eclipse, at midnight for a dawn eclipse).[122] Otherwise we know of no instances in Greco-Roman sources of either specific predictions of winds, and particularly of wind *directions*, during eclipses, or methods of making such predictions, though we shall presently see that Ptolemy was probably aware of the existence of such methods. The astrologer Hephaistion of Thebes (c. A.D. 400) attributes to the "Egyptians of old" a doctrine that the direction from which the wind blows at the onset of an eclipse indicates the country that will be adversely affected by it, whereas the direction at the end of the eclipse indicates the country that will be favorably affected; thus a *change* of wind direction was considered normal during an eclipse.[123] Hephaistion's "Egyptians" were almost certainly Greco-Egyptian astrological authorities dating from the Hellenistic period, so they are not very remote chronologically or culturally from the builders of the Antikythera Mechanism.[124]

The verb in the Back Plate Inscription translated as "to veer," περιίστασθαι, is not especially common, and a search of ancient Greek literature by means of the *Thesaurus Linguae Graecae* fails to turn up any passage in which the verb is used in connection with eclipse phenomena. There are, however, instances of its use in connection with shifting wind directions,[125] in-

115 [Aristotle], *Problemata* 26.23; Pseudo-Theophrastos, *De Signis* 37; Ptolemy, *Tetrabiblos* 2.14.10 (Hübner).

116 Ptolemy, *Tetrabiblos* 2.14.9 (Hübner) —possibly an interpolated sentence— and Hephaistion, *Apotelesmatica* 1.3 (Pingree 33).

117 Pseudo-Theophrastos, *De Signis* 29.

118 Pseudo-Theophrastos, *De Signis* 32.

119 Ptolemy, *Tetrabiblos* 2.13.4 (Hübner).

120 Pseudo-Theophrastos, *De Signis* 5-8.

121 Pseudo-Theophrastos, *De Signis* 31.

122 A close parallel to this passage is in [Aristotle], *Problemata* 26.18.

123 Hephaistion, *Apotelesmatica* 1.21.

124 Pingree 1974.

125 For others, see [Aristotle], *Problemata* 26.31 (943b29) and 26.56 (947a3).

cluding a striking parallel to the formula of our inscription in Aristotle, *Meteorologica* 365a6:

“οἱ δ ̓έτησίαι περιίστανται τοῖς μὲν περὶ δυσμὰς οἰκοῦσιν ἐκ τῶν ἀπαρκτίων εἰς θρασκίας καὶ ἀργέστας καὶ ζεφύρους… τοῖς δὲ πρὸς ἕω περιίστανται μέχρι τοῦ ἀπηλιώτου“.
(“For people who live in the west, the Etesian winds veer from *aparktias* to *thraskias* and *argestês* and *zephyros*… while for those who live in the east, they veer to *apêliôtês*“.)

Aristotle’s use of this construction enables us to dismiss an objection that has been raised against interpreting the inscription’s wind-directions as references to actual winds, namely that the horizon directions associated with Greek wind names were (as in English) the directions *from which* the winds blow, so that the preposition πρός, “towards,“ would never be used with a wind-direction name to mean the wind bearing that name.[126] One would indeed never write that a wind blows πρὸς ἀπηλιώτην, “towards *apêliôtês*“ meaning towards the east, since the wind that blows in that direction is called *zephyros*, the *west* wind. But it does make sense in Greek, as in English, to write that the wind direction shifts from south to east (ἀπὸ νότου πρὸς ἀπηλιώτην, or using Aristotle’s equivalent expressions, εἰς ἀπηλιώτην or μέχρι ἀπηλιώτου) meaning that what was initially a south wind (blowing north) has become an east wind (blowing west).

However, before hastening to the conclusion that the vocabulary of our inscription was associated with winds but not with eclipse obscurations, we ought to take note of *POxy. astron.* 4137, a first century AD Greek papyrus fragment from Oxyrhynchus that, like most literary and “paraliterary“ papyri, is not at present in the *Thesaurus Linguae Graecae*.[127] This preserves part of a canon of predictions of lunar eclipses dating to the mid first century AD, the only such text in Greek that we currently possess. The predicted data include the date of the eclipse, its magnitude and duration, the directions of obscuration (προσνεύσεις, “inclinations“) at the beginning, middle, and end of the eclipse, and the Moon’s position relative to a fixed star. The directions of obscuration of the partial lunar eclipse of December 10/11, AD 56 are described thus in lines 4-9:

“ἡ μὲν ο[ὖν πρόσν(ευσις) πρώτου] ἐγλ(ελοιπότος) ἔσται μεταξὺ μ̣[εσημβρίας καὶ] ἀνατολ(ῆς)· περιστήσε[ι δὲ πλεῖστον] ἐγλελοιπὸς πρόσν̣(ευσιν) [ὡς πρὸς μεσημβ(ρίαν)]· ἔσχατον δ ̓ἀναπ[ληρούμενον ὡς] μεταξὺ μεσημ(βρίας) καὶ δ̣[ύσεως.]“
(“The [inclination of the beginning] of obscuration will be between s[outh and] east; at [greatest] obscuration it will cause the inclination to veer [towards the south]; at final cle[aring] towards south and w[est.]“)

Although some uncertainty may adhere to the exact wording of the gaps between the preserved part-lines, it is certain that the incomplete word περιστησε in line 6 is either περιστήσεται, the future tense of περιίστασθαι, “it will veer“ or (as restored here), περιστήσει, the future

126 Papathanassiou 2010, 546.

127 Jones 1999, 1.87-94, and 2.16-17.

of the verb's transitive form, "it will cause to veer" with the direction of obscuration being either the subject or the direct object.

The terminology of "inclinations" found in this papyrus is only intelligible to us because Ptolemy explains it in *Almagest* 6.11, where as part of the subject of eclipse theory and prediction he provides a mathematical treatment of "inclinations," interpreted as meaning the point on the horizon intersected by the great circle passing through the centers of the lunar disk and the Earth's shadow (for lunar eclipses) or the centers of the solar and lunar disks (for solar eclipses). He remarks that the reason for determining these directions is that they are regarded as having a certain "signification" (ἐπισημασία), a term that had the technical meaning of a "weather-prediction sign" or a change in the weather associated with such a sign.[128] Although Ptolemy offers no details, it is tempting to conjecture that some correlation was presumed to exist between the directions of obscuration and the wind directions at the various stages of the eclipse. Such a scheme would explain why the Hephaistion's "Egyptian" scheme involves interpreting wind directions at both the start and the finish of an eclipse.

Thus we cannot decide simply on the basis of the wording of the "directions" sentences in the Back Plate Inscription whether their predictions refer to directions of obscuration or to winds. *Prima facie* the interpretation as directions of obscuration seems to be favored by the fact that these directions are an objectively valid, "astronomical" consequence of the conditions giving rise to an eclipse, whereas forecasts of wind directions would imply a physical (or even divinatory) framework that is otherwise not explicit in what we know of the Mechanism's displays and functions; for although parapegmata were instruments of weather prediction, the Mechanism's Parapegma Inscription did not contain explicit statements of weather changes but only the astronomical phenomena on which such predictions could have been based. But these considerations that weigh on the side of obscuration directions will count for nothing unless the specific content of the statements as well as the index letters associated with them turn out to make sense in terms of the actual characteristics of a series of eclipses occurring in the course of a Saros cycle.

As a first step in testing the hypothesis that the sentences refer to obscuration directions, we consider the meaning of the directional terms in the inscription. In technical contexts Greek wind names were associated with "windroses," that is, systems of either eight or twelve equally distributed horizontal directions.[129] Though several variations on windroses are attested in Greco-Roman sources, it is probable that the one assumed in the Back Plate Inscription was close to one of the following reconstructions (the twelvefold one being essentially the windrose ascribed to the Hellenistic geographer Timosthenes) (Fig. 4.16).[130]

128 Neugebauer 1975, 1.141-142; Lehoux 2004.

129 Rehm 1916.

130 As Crowther (Freeth 2014, Note S2, 2) points out, the presence of θραικίας among

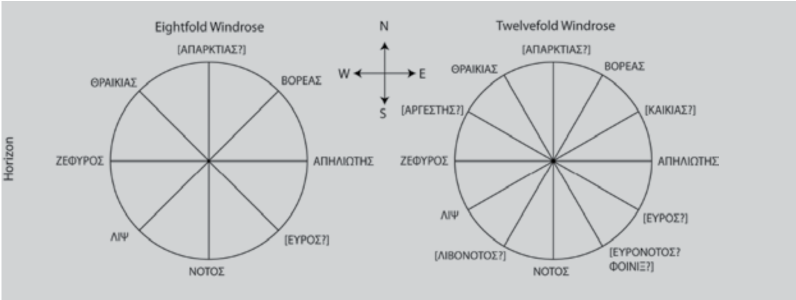

Figure 4.16: *Reconstructed eight-direction and twelve-direction windroses for the directions attested in the Back Plate Inscription*

Of course if one is applying such a scheme to the solar or lunar disk as seen from below, the diagrams have to be mirror-reversed (Fig. 4.17).

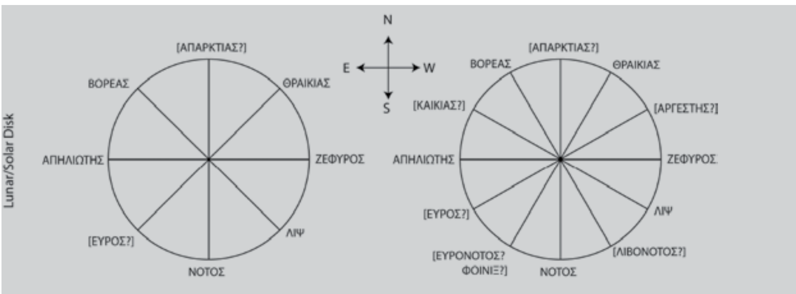

Figure 4.17: *Reconstructed windroses oriented for celestial directions*

Now if we number the preserved paragraphs of the inscription 1 through 5, the directions of the statement in paragraph 1 are both lost, while the remainder would map on the windroses as shown in Fig. 4.18.

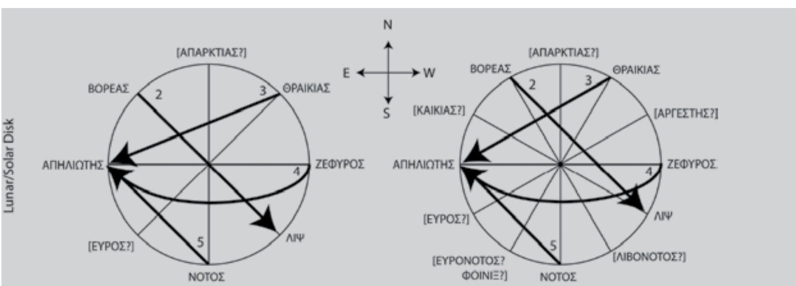

Figure 4.18: *The shifts of direction in the Back Plate Inscription*

the wind directions in the inscription favors a twelve-direction windrose since attested eight-direction systems did not include this wind.

The diagrams incidentally explain why an intermediate direction is specified in paragraph 4 only: whereas in most cases —all cases for the twelve-direction system— one may presume that the "veering" sweeps out the shorter arc around the circle, here the starting and finishing directions are diametrically opposite so that the sense of the shift has to be explicitly stated.

A basic rule is that the obscuration in lunar eclipses tends westward, but eastward in solar eclipses. Hence paragraphs 3-5 would refer to solar eclipses, but paragraph 2 would have to refer to lunar eclipses. Aside from being in conflict with our analysis of the index letter groups, this is troubling for two reasons. First, in an inscription encompassing both lunar and solar eclipses, one would expect the two kinds to be dealt with in separate sections, whereas here we seem to have both kinds treated in what, according to its position on the plate, would seem to be the last quarter of the inscription. And more seriously, solar eclipses do not repeat their directions of obscuration after 223 months — as we have already remarked with respect to eclipse times, the Saros is only meaningful as a period of repetition for solar eclipse *possibilities*, not actual solar eclipses visible from a particular region of the Earth because of the effects of parallax. Predictions of directions of obscuration for solar eclipses based on a repeating Saros cycle could only refer to a highly idealized model in which the effect of parallax is ignored or grossly simplified and the diameter of the lunar disk considerably exaggerated. Such predictions would have scarcely any relation to actual eclipses observable in any locality.

If, notwithstanding these difficulties, the paragraphs are describing the shifting directions of obscuration of eclipses, one would have to conclude that they cannot be in an ecliptic frame of reference, that is, east and west are not reckoned as parallel to the ecliptic. Since the Moon is always close to one of its nodes at an eclipse, the obscuration always crosses the eclipsed body in a direction inclined approximately 5° from the ecliptic, whereas our diagrams would imply much more deviant paths. The ecliptic frame of reference is the only one that preserves directions of obscuration in the long term through a series of eclipses —properly, just lunar eclipses!— at Saros intervals, because the relative orientation of the Sun and Moon would not stay the same relative to the celestial equator or the observer's horizon. Since the Saros exceeds 18 solar years by just about 11 days, however, the configuration would not change by much in an equatorial frame of reference after a single Saros. One might contemplate the possibility that the directions in the text are reckoned such that east and west are parallel to the celestial equator, and that the predictions were at best valid for a run of a few Saros cycles around the epoch for which they were calibrated. For eclipses occurring close to the equinoxes and at the right node, the path of obscuration deviates from the equator by almost 30°, perhaps enough to make a predicted course "from *notos* to *apêliôtês*" or "from *boreas* to *lips*" credible. Ptolemy's hypersophisticated "inclinations" projected by great circles upon the horizon are out of the question.

Moreover, we cannot reconcile the groupings of letters in the index lines, as we have reconstructed them, with any rational prediction of obscuration directions according to even an idealized, parallax-free eclipse theory. The trend of the obscuration, at least in an ecliptic frame of reference, should be northward for all eclipses having the Moon near the ascending node, and southward for all eclipses having it near the descending node. We have seen, however, that solar EPs near opposite nodes are grouped together in the inscription's paragraphs.[131]

We may sum up as follows. (1) Any competent Hellenistic astronomer would have known that it does not make astronomical sense to offer predictions of obscuration paths of solar eclipses following a Saros cycle, yet if the statements in the inscription are about obscuration paths, the surviving ones are for solar eclipses. (2) To the extent that a Saros cycle is a suitable framework for predicting obscuration paths —i.e. for lunar eclipses— it works best if the frame of reference is the ecliptic, because the Saros is not close enough to an integer number of solar years to preserve paths relative to the equator over more than one or two cycles, while the configurations relative to the horizon are not preserved at all. Yet the pairs of directions in some of the paragraphs of the inscriptions deviate too far from due east-west orientation to be obscuration paths in an ecliptic frame of reference. (3) The cells indicated by the index letter groups would not have corresponded to eclipses with similar obscuration paths.

Taking into consideration the level of astronomical knowledge reflected in the mechanical design of the Mechanism, it is difficult to believe that the astronomer-mathematician responsible for the scientific content of its inscriptions would have bungled the prediction of obscuration paths so badly. We are therefore led to prefer the alternative interpretation of the statements in the inscription as predictions of winds attending the eclipses. While of course a correlation between nodal elongations at eclipses (or EPs) and changes of wind direction does not really exist, ancient meteorological theories made such a correlation perfectly reasonable.[132]

131 Freeth 2014, Note S2, 4-6 attempts, unconvincingly in our view, to maintain that the predictions of the inscription are of eclipse obscurations. In this context he does not mention the fact that the prediction associated with the EPs in line 9 gives an impossible direction for solar eclipses.

132 Montelle 2011, 152 draws attention to how Hellenistic astrological authors mutated the Mesopotamian practice of treating directions of eclipse obscurations as data for interpreting eclipse omens into one using wind directions, and suggests that this tendency may have been motivated by the fact that directions of obscuration do not have a very wide range of variation, limiting their prognostic usefulness.

4.12 Sizes and colors

The paragraphs of the inscriptions may be summarized as follows:

Paragraph	*Directions*	*Size*	*Color*
1 (lines 0-4)	?	small	?
2 (lines 5-9)	NNE to WSW	intermediate	black
3 (lines 10-18)	NNW to E	large?	red
4 (lines 19-29)	W *via* S to E	intermediate	black
5 (lines 30-36)	S to E	small?	black

The directions, as already noted, do not reveal any obvious pattern. The sizes, however, show, if the readings for the third and fifth paragraphs are correct, a symmetrical progression from small to large to small again.[133] The unstated subject to which these characteristics are attributed is grammatically feminine plural, so ἐκλείψεις ("eclipses") is possible but "winds" (ἄνεμοι) is not. While it is tempting to think of magnitudes or durations of obscuration, once again we run into the problem that the Saros does not bring about repetitions of these aspects of solar eclipses because they are strongly affected by parallax.[134] We suppose that they may be understood as a qualitative "upper bound" for both magnitudes and durations.

The readiest interpretation of the color predictions is that they refer to the appearance of the Sun's disk during the eclipse. For the third color in paragraph 1, possibilities that we can think of that have the surviving -ινον termination include πράσινον ("light green"), σκοτεινόν ("dark"), and κόκκινον ("scarlet"). In the other paragraphs, the colors seem to correlate with the size predictions in that the "large" eclipses are assigned red and the "medium" and southerly "small" eclipses are assigned black.

Babylonian lunar eclipse omen texts frequently cite the color of the eclipsed luminary as an element in the protases ("if" clauses), and this, like eclipse winds, passed into the treatment of eclipses in Hellenistic astrology.[135] Hephaistion (1.21) tells us that his "Egyptians of old" assigned various dire consequences to total eclipses —he does not discriminate between lunar and solar— according as the color is "black" (μέλαν), "red" (ἐρυθρόν), "whitish" (ὑπόλευκον), "violet" (ἰοειδές), or "golden" (χρυσοειδές).[136] Ptolemy (*Tetrabiblos* 2.10 Hübner) does not

133 This was noticed by Freeth 2014, Note S2, 6, though he assumes a six paragraph reconstruction with another "large" paragraph between our numbers 3 and 4.

134 Freeth 2014, Note S2, 6 interprets them as magnitudes.

135 Rochberg-Halton 1988, 55-57. Francesca Rochberg informs us by personal communication that colors are less prominent in the Babylonian solar eclipse omens, though the color of the Sun's light (e.g. "red" or "cool") is sometimes a factor in the omen.

136 In 1.23 Hephaistion gives σκοτεινόν as one of the possible colors of Sirius at its first

restrict the relevance of colors to total eclipses, and in fact he attributes the same significance not only to the color of the luminary itself but to that of nearby optical phenomena such as rods and halos. His colors include "black" (μέλαν), "greenish yellow" (ὑπόχλωρον), "white" (λευκόν), "ruddy" (ὑπόκιρρος), "yellow" (ξανθόν), and "variegated" (ποικίλον).

Outside of the Back Plate Inscription, we are not aware of any Greco-Roman source that offers predictions of eclipse colors or indeed states that such colors are predictable. It is conceivable that certain schemes found in Indian astronomical texts for predicting changing colors through the course of an eclipse derive from Greek astronomy.[137] Much more relevant to our inscription, however, are medieval Arabic and Hebrew tables that predict colors of both solar and lunar eclipses as a function of nodal elongation, that is, a criterion closely related to the one determining the EP groups in our inscription.[138] The color schemes tend to run from black at the nodes themselves through reddish, yellowish, and grayish hues as the absolute elongation increases, in other words a similar pattern to the one apparent in our inscription. Goldstein offers remarks that have equal bearing to the color predictions in our inscription:[139]

"From a modern point of view, there should not be a table for colors of solar eclipses; for lunar eclipses, the modern theory bears little relationship to the medieval table... Although the entries in the medieval tables do not conform to modern data, this tradition may well have affected the perception of reality by those who accepted it".

Following Pingree, Goldstein conjectures that the earliest tables for predicting eclipse colors were in the *zij* of al-Khwarizmi (c. A.D. 830) and that the doctrine had an Indian origin. It now appears plausible that the ultimate source was Greek, and if there was an Indian intermediary, it was different from the known Indian schemes that prescribe changing colors to different stages of an eclipse.

morning appearance.

137 Montelle 2011, 219 and 241-242.

138 Goldstein 2005.

139 Goldstein 2005, 12; Pingree 1976, 166.

4.13 General remarks on the inscriptions of the Mechanism's back face

The layout of the back face of the Antikythera Mechanism seems to have been designed to give immediate visual impact to a parallelism between the information displayed in its top and bottom halves: each spiral represents an astronomically meaningful cycle of comparable length comprising whole numbers of synodic months, in one case equated to a whole number of solar years, and in the other, to whole numbers of anomalistic and dracontic months. If the conjectural Callippic Dial was present, then a second parallelism subsisted between subsidiary dials within each spiral representing the smallest multiple of the spiral's cycles that contained a whole number of days; and the Games Dial too is a representation of the smallest multiple of *solar years* comprising a whole number of days.

The inscriptions, on the other hand, add quite contrasting overlays of meaning to each half. The Metonic Spiral translates a purely astronomical relation between mean lunar and solar longitudinal periods into a calendar, and moreover a regional calendar that had no distinctive role in Greek astronomy (as the Athenian and Egyptian calendars did) and that would not have been well known outside the specific localities where it was in use at the time that the Mechanism was made. Geminos's chapter "On Months" (*Introduction to the Phenomena* 8) is illuminating here for its treatment of calendars as human inventions based on astronomical facts but fundamentally determined by the requirements set by the societies that use them. Again, the inscriptions of the Games Dial refer to athletic competitions, that is, *social* phenomena that had four-year and two-year periodicities unconnected with astronomy; for example, the fact that a competition was held at Olympia every four years had nothing to do with the 365 1/4 day solar year.

The inscriptions of the lower dials, on the other hand, relate them not to social but to natural phenomena, namely eclipses. The decision to represent the Saros cycle as, above all, a cycle of eclipse possibilities was not as obvious as it might at first appear.[140] Among the three ancient Greco-Roman writers on astronomy who discuss the Saros or the Exeligmos, it is only the encyclopedist Pliny the Elder (*Naturalis Historia* 2.56) who explicitly characterizes the Saros as an eclipse period, whereas Geminos (*Introduction to the Phenomena* 18) and

140 We do not know of another Greco-Roman text or artefact that definitely employs a subdivision of the Saros into a fixed arrangement of eclipse possibilities at 6-month and 5-month intervals, though the principle was likely applied in a first century BC canon of predicted lunar eclipses fragmentarily preserved in a Demotic Egyptian papyrus (Steele 2000b, 89). An anonymous third-century AD commentator on Ptolemy (Jones 1990, 22-23) and Plutarch, *De facie in orbe lunae* 20, 933 E both discuss such a distribution with the more accurate 5458-month lunar anomalistic period of the Babylonian System B lunar theory, which was known to Hipparchus.

Ptolemy (*Almagest* 4.2) speak of the Saros and Exeligmos as periods of synodic months that approximately comprise whole numbers of anomalistic and draconitic months, in other words, theoretically meaningful period relations for the Moon's motion rather than periods of lunisolar phenomena. In designing the Mechanism's gearwork, its inventors exploited the Ptolemy-Geminos interpretation of the Saros as the basis for reproducing lunar anomaly, but the exterior makes only a slight gesture towards this theoretical side of the Saros in the form of the unlabelled fiducial marks inscribed along the inner rim of the Saros Dial that apparently indicate the Full Moon cycle.[141]

The fact that every cell of the Saros Dial that contains a glyph has an index letter implies that the complete Back Plate Inscription contained information supplementing both lunar and solar eclipse possibilities; however, we have only a little over half of the text from the lower right side of the plate, which, as we have seen, appears to have been devoted entirely to solar eclipse possibilities. Whether the descriptions of lunar eclipses had the same format and contents as the solar paragraphs, and whether they were likewise grouped solely according to the criterion of lunar latitude without taking into account which node the Moon was near have to remain open questions.

Knowing, as they surely did, that the Saros could not predict whether a solar eclipse possibility would be accompanied by an observable eclipse, let alone its duration and magnitude, the designers could simply have left the predictions of solar eclipse possibilities as bare statements with at most a time of syzygy. Instead, they appear to have offered predictions of optical or meteorological circumstances that they expected would accompany a solar eclipse *if* an eclipse occurred at an eclipse possibility. The correspondences between these predictions and the eclipse phenomena invoked in the astrological literature are surely not accidental. We see it as an indication that the Mechanism was fashioned to represent and simulate a Hellenistic cosmology in which astronomy, meteorology, and astral divination were intertwined.

141 Freeth, Jones, Steele, and Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 39-40.

Acknowledgements

The authors acknowledge Dr. Tony Freeth's involvement in earlier stages (up to 2012) of the study of the inscriptions published in the present paper, including provision of some CT images and comments on the structure of the Back Cover Inscription. We believe we have carefully acknowledged in the text of the paper any work on the inscriptions to which he particularly contributed. The reading of the Back Plate Inscription builds on earlier work by Emmanouel Georgoudakis in collaboration with Yanis Bitsakis at the Cultural Foundation of the National Bank of Greece, Center for History and Palaeography. Christián Carman shared with the authors his work on the readings and original distribution of the eclipse glyphs. The authors also thank the National Archaeological Museum of Athens, the Deutsches Archäologisches Institut (Athens Department), the Bayerische Staatsbibliothek, and the Adler Planetarium for access to photographs and archival materials. They are also very grateful for discussion with, and support from, other members of the Antikythera Mechanism Research Project.

Bibliography

- Anastasiou, M., Seiradakis, J.H., Carman, C.C., Efstathiou, K. (2014), "The Antikythera Mechanism: The Construction of the Metonic Pointer and the Back Plate Spirals", *Journal for the History of Astronomy* 45: 1-26. Supplementary Appendices A and B accompanying online version.
- Battistoni, F. (2011), "Time(s) for Tauromenion: The Pilaster with the List of the Stratagoi (IG XIV 421) - The Antikythera Mechanism", *Zeitschrift für Papyrologie und Epigraphik* 179: 171-188.
- Britton, J.P. (2007), "Calendars, Intercalations and Year-Lengths in Mesopotamian Astronomy", ın Steele, J.M. (ed.), *Calendars and Years: Astronomy and Time in the Ancient Near East.* Oxford, 115-132.
- Cabanes, P. (1976), *L'Épire de la mort de Pyrrhos à la conquête romaine (272-167 av. J.C.)*. Paris.
- Cabanes, P. (1988), "Les concours des Naia de Dodone", *Nikephoros* 1: 49-84.
- Cabanes, P. (2007), "Recherches sur le calendrier corinthien en Épire et dans les régions voisines", in Cabanes, P., Drini, F., *Corpus des inscriptions grecques de l'Illyrie méridionale et d'Épire 2. Inscriptions de Bouthrôtos.* Études épigraphiques 2 : 275-288.
- Cabanes, P. (2011), "Le Mécanisme d'Anticythère, Les NAA de Dodone, et Le Calendrier Épirote", *Tekmeria* 10: 249-260. http://tekmeria.org/index.php/tekmiria/article/view/278
- Carman, C.C., Evans, J. (2013), "On the Epoch of the Antikythera Mechanism", Paper presented at workshop on The Antikythera Mechanism: Science and Innovation in the Ancient World, Lorentz Center, Leiden, June 17-21, 2013. http://www.conicet.gov.ar/new_scp/detalle.php?keywords=&id=21332&congresos=yes&detalles=yes&congr_id=2064637
- Carman, C.C., Evans, J. (2014),. "On the Epoch of the Antikythera Mechanism and its Eclipse Predictor", *Archive for History of Exact Sciences* 68: 693-774.
- Freeth, T. (2014), "Eclipse Prediction on the Antikythera Mechanism", *PLOS One (Public Library of Science)* 9.7.e103275. http://dx.plos.org/10.1371/journal.pone.0103275
- Freeth, T., Bitsakis, Y., Moussas, X., Seiradakis, J.H., Tselikas, A., Mangou, H., Zafeiropoulou, M., Hadland, R., Bate, D., Ramsey, A., Allen, M., Crawley, A., Hockley, P., Malzbender, T., Gelb, D., Ambrisco, W., Edmunds, M.G. (2006), "Decoding the ancient Greek astronomical calculator known as the Antikythera Mechanism", *Nature* 444: 587-591. Supplementary information, http://www.nature.com/nature/journal/v444/n7119/suppinfo/nature05357.html.
- Freeth, T., Jones, A., Steele, J.M., Bitsakis, Y. (2008), "Calendars with Olympiad display and eclipse prediction on the Antikythera Mechanism", *Nature* 454: 614-617. Supplementary Notes (amended June 2, 2011), http://www.nature.com/nature/journal/v454/n7204/extref/nature07130-s1.pdf.
- Gautschy, R. (2012), "Directions of Obscuration in Babylonian Eclipse Records", *Journal for the History of Astronomy* 43: 479-489.
- Goldstein, B.R. (2005), "Colors of Eclipses in Medieval Hebrew Astronomical Tables", *Aleph* 5: 11-34.
- Gray, S.L., Harrison, R.G. (2013), "Diagnosing Eclipse-Induced Wind Changes", *Proceedings of the Royal Society* A. : Mathematical, Physical and Engineering Sciences 468: 1839-1850..

- Huber, P., Meis, S. De (2004), *Babylonian Eclipse Observations from 750 BC to 1 B.C.* Milan.
- Hunger, H. (1976), "Astrologische Wettervorhersagen", *Zeitschrift für Assyriologie* 66: 234-260.
- Iversen, P. (2011), "A Clockwork Bronze: The Calendar and the 'Olympiad Dial' on the Antikythera Mechanism". Paper presented at History of Science Society annual meeting, Cleveland, November 2-5, 2011. http://hssonline.org/meetings/annual-meeting-archive/
- Iversen, P. (2013a), "The Antikythera Mechanism and the Corinthian Family of Calendars". Paper presented at American Philological Association annual meeting, Seattle, January 3-6, 2013. http://apaclassics.org/annual-meeting/144/144th-annual-meeting
- Iversen, P. (2013b), "The Antikythera Mechanism and Rhodes". Paper presented at workshop on The Antikythera Mechanism: Science and Innovation in the Ancient World, Lorentz Center, Leiden, June 17-21, 2013. http://www.lorentzcenter.nl/lc/web/2013/570/abstracts.php3?wsid=570&type=presentations&venue=Oort
- Iversen, P. (2015), "The Heloreia Festival at Halaisa Archonideia, Tauromenion, and Syracuse". Paper presented at Society for Classical Studies annual meeting, New Orleans, January 8-11, 2015. http://apaclassics.org/annual-meeting/146/146th-annual-meeting
- Iversen, P. (forthcoming, a), "The Calendar on the Antikythera Mechanism and the Corinthian Family of Calendars".
- Iversen, P. (forthcoming, b), "The Antikythera Mechanism, Rhodes and Epeiros".
- Jones, A. (1990), *Ptolemy's First Commentator*. Transactions of the American Philosophical Society 80.7.
- Jones, A. (1997), "Studies in the Astronomy of the Roman Period. I. The Standard Lunar Scheme", *Centaurus* 39: 1-36.
- Jones, A. (1999), *Astronomical Papyri from Oxyrhynchus.* Memoirs of the American Philosophical Society 233. 2 vols in 1. Philadelphia.
- Lehoux, D., "Impersonal and Intransitive ΕΠΙΣΗΜΑΙΝΕΙ", *Classical Philology* 99: 78-85.
- Mitford, T.B. (1961), "Further Contributions to the Epigraphy of Cyprus", *American Journal of Archaeology* 65: 93-151.
- Montelle, C. (2011), *Chasing Shadows. Mathematics, Astronomy, and the Early History of Eclipse Reckoning.* Baltimore.
- Neugebauer, O. (1957), *The Exact Sciences in Antiquity.* 2nd ed. Providence.
- Neugebauer, O. (1975), *A History of Ancient Mathematical Astronomy.* 3 vols. Berlin.
- Neugebauer, O., Hoesen, H.B. van (1959), *Greek Horoscopes.* Memoirs of the American Philosophical Society 48. Philadelphia.
- Papathanassiou, M.K. (2010), "Reflections on the Antikythera Mechanism Inscriptions", *Advances in Space Research* 46: 545-551.
- Pingree, D. (1974), "Petosiris, pseudo-", *Dictionary of Scientific Biography* 10: 547-549.
- Pingree, D. (1976), "The Indian and Pseudo-Indian Passages in Greek and Latin Astronomical and Astrological Texts", *Viator* 7: 141-195.
- Price, D. (1959), "An Ancient Greek Computer", *Scientific American* June 1959: 60-67.
- Price, D. (1974), *Gears from the Greeks.* Transactions of the American Philosophical Society N.S. 64.7.
- Rehm, A. (1916), "Griechische Windrosen", *Sitzungsberichte der Bayerischen Akademie*

der Wissenschaften, Philosophisch-historische Klasse 1916.3.

- Rochberg-Halton, F. (1988), *Aspects of Babylonian Celestial Divination: The Lunar Eclipse Tablets of Enūma Anu Enlil.* Archiv für Orientforschung Beiheft 22. Horn.
- Seider, R. (1967), *Paläographie der griechischen Papyri, Band I: Tafeln, Erster Teil: Urkunden.* Stuttgart.
- Steele, J.M. (2000a), "Eclipse Prediction in Mesopotamia", *Archive for History of Exact Sciences* 54: 421-454.
- Steele, J.M. (2000b), *Observations and Predictions of Eclipse Times by Early Astronomers.* Archimedes 4. Dordrecht.
- Steele, J.M. (2011), "Visual Aspects of the Transmission of Babylonian Astronomy and its Reception into Greek Astronomy", *Annals of Science* 68: 453-465.
- Svoronos, I.N. (1903a), Ὁ Θησαυρὸς τῶν Ἀντικυθήρων. Athens. Republished in Svoronos, I.N. (1908), *Τὸ ἐν Ἀθήναις Ἐθνικὸν Μουσεῖον.* Athens.
- Svoronos, I.N. (1903b), *Die Funde von Antikythera*, Athens, 1903. Republished in Svoronos, I.N. (1908), *Das Athener Nationalmuseum*. Athens.
- Theofanidis, I. [1927-1930], "Ἁγίου Παύλου (πλοῦς)", *Μεγάλη Στρατιωτικὴ καὶ Ναυτικὴ Ἐγκυκλοπαίδεια* 1: 83-96 [pp.. 89-96 are erroneously numbered 97-104].
- Theofanidis, I. (1934), "Sur l'instrument en cuivre dont les fragments se trouvent au Musée Archéologique d'Athènes et qui fut retiré du fond de la mer d'Anticythère en 1902", *Πρακτικὰ τῆς Ἀκαδημίας Ἀθηνῶν* 9 : 140-149.
- Wright, M.T. (2004), "The Scholar, the Mechanic and the Antikythera Mechanism: Complementary Approaches to the Study of an Instrument", *Bulletin of the Scientific Instrument Society* 80: 4-11.
- Wright, M.T. (2005), "Counting Months and Years: The Upper Back Dial of the Antikythera Mechanism", *Bulletin of the Scientific Instrument Society* 87: 8-13.
- Wright, M.T. (2006), "The Antikythera Mechanism and the Early History of the Moon-Phase Display", *Antiquarian Horology* 29: 319-329.
- Zafeiropoulou, M. (2006), "Συλλογή Χαλκών: Ο Μηχανισμός των Αντικυθήρων", *2ο Διεθνές Συνέδριο Αρχαίας Ελληνικής Τεχνολογίας , Πρακτικά (2nd International Conference on Ancient Greek Technology Proceedings)*. Athens, 829-832.
- Zapheiropoulou [Zafeiropoulou], M. (2012), "Old and New Fragments of the Antikythera Mechanism and Inscriptions", in Kaltsas, N., Vlachogianni, E., Bouyia, P. (eds), *The Antikythera Shipwreck: the ship, the treasures, the mechanism.* Exhibition catalogue. Athens, 241- 248.