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Astronomical Records in the Goguri Annal of the Three Kingdoms Period

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It is known that Chang-Hwa Park (1889–1962) transcribed a chronicle of the Goguryeo kingdom (BC 37–AD 668) of Korea (hereafter Goguri annal) from literature of the time that is no longer available. However, the authenticity of his transcription remains disputed. This study attempts to verify whether the Goguri annal is a pseudograph by analyzing the astronomical records in the annal. Although the Goguryeo kingdom fell in the year 668, the Goguri annal contains records up to the year 536. In this study, we have classified the astronomical records into eight categories and clustered them into two groups: a calendrical data group of reign-name and calendar date categories, and a celestial phenomena group of solar eclipse, trespass, comet, daylight appearance of Venus, meteor/meteorite, and other categories. The records of each category have been compared with those of the *Samguksagi* (History of the Three Kingdoms), Chinese chronicles, and with the results of modern computations wherever possible. From this comparison, we have not found any critical record that would indicate that the Goguri annal is a pseudograph, although the same astronomical records, with the exception of a few, are also found in the *Samguksagi* and Chinese chronicles.

Keywords: historical astronomy, astronomical record, Goguryeo kingdom, *Samguksagi*

1. INTRODUCTION

Korea has numerous astronomical records since the Three Kingdoms (Silla, Goguryeo, and Baekje) period (BC 54–AD 935). Although the *Jeungbo-Munheon-Bigo* (Revised and Enlarged Complete Examination of Documents) contains astronomical records from the Three Kingdoms period, the *Samguksagi* (History of the Three Kingdoms; hereafter Sagi) is the primary source of these records. This book, which comprises a chronological table, annals of each kingdom (i.e., Silla, Goguryeo, and Baekje annals), monographs, and biographies, was compiled by Bu-Sik Kim (1075–1151) and his colleagues in 1142. Hence, the authenticity of the astronomical records of the Sagi, particularly the solar eclipse records of the early era, has been debated (e.g., Park & La 1994; Lee 2008; Stephenson 2013). The main reason for this controversy is that the early solar eclipse records in the Sagi are the same as those of the Chinese chronicles at that time, including eclipses that did not occur on Earth.

Chang-Hwa Park (1889–1962), who is widely known as the writer of the *Hwarangsegi* (Annals of the Warrior Youth of the Silla Kingdom), also wrote the historical materials of the Goguryeo kingdom (BC 37–AD 668) (Park 2007). Of these materials, the *Goguryeo-Sacho* (Extracted History of the Goguryeo Kingdom) and *Goguryeo-Saryak* (Brief History of the Goguryeo Kingdom) were translated into Korean by Kim (2008). In this study, we have referred to this Korean-translated version. In addition, we call those histories as the "Goguri annal", following the expression of Kim (2008) to distinguish it from the "Goguryeo annal" of the Sagi. Although

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the Goguryeo kingdom fell in 668, the Goguri annal contains records up to the year 536. It is known that both annals are transcriptions of the then existing literature that are no longer available. However, the authenticity of the annals has been disputed. Park (2018) suggested that the Goguri annal was written based on the Sagi without referring to other unknown texts, although he found that the annal contains some records that did not exist in the known chronicles.

The study aims to verify the authenticity of the Goguri annal in terms of the astronomical records contained in it. To this end, the astronomical records were extracted from the Goguri annal by referring to the work of Kim (2008) and were classified into eight categories: reign-name, calendar date, solar eclipse, trespass, comet, daylight appearance of Venus, meteor/meteorite, and other. Further, these categories were clustered into two groups: a calendrical data group of reign-name and calendar date categories, and a celestial phenomena group of the remaining categories. In our study, the Goguri annal contains 111 astronomical records. However, some records are duplicated not only between both groups but also within each group, as can be understood from the following sections.

2. CALENDRICAL DATA

2.1 Reign-Name

Table 1 summarizes the reign-names extracted from the Goguri annal. In the table, columns 1, 2, and 3 are the sequential number (no.) starting with the letter R, year, and the reign-name enforced in that year. The last column lists the names of the kings of the Goguryeo kingdom from the Sagi when the corresponding reign-names were enforced, except for No. R07, which refers to that of China. In the annals of the Sagi, only the reign-names of the Silla have been recorded since 536 (refer to Lee et al. 2021). On the other hand, the reign-name that shows agreement with previous studies is *Yeongrak* (no. R06) during the reign of King Gwanggaeto (r. AD 391–412), although this name was not recorded in the Sagi. Interestingly, the reign-names of *Dongmyeong*, *Yurigwangmyeong*, *Daemu*, *Mobon*, and *Anjang* (nos. R01, R02, R03, R04, and R08, respectively) show similarities in the names of kings in the Goguryeo annal of the Sagi, Dongmyeongseong, Yurimyeong, Daemushin, Mobon, and Anjang, respectively. In addition, although the Goguri annal states that the reign-name of *Mobon* was introduced in AD 68, King Mobon reigned from AD 48 to 53 and King Taejo reigned for 94 years from AD 53 to 146 according to the Sagi. Further, the reign-name of *Geonsi* (*Jianshi* in Chinese pronunciation) was that of the Later Yan dynasty (AD 384–407) in China, as mentioned in the Goguri annal. Finally, Jung (1998) suggested that the reign-name of the *Geonheung* found in an epigraph is that of the Goguryeo kingdom enforced around the year 532, which shows a discrepancy with the *Daejang* (no. R09).

Table 1. Summary of the reign-name records from the Goguri annal

No.	Year	Reign-name	Note
R01	BC 37	*Dongmyeong*	Dongmyeongseong (BC 37–BC19)
R02	18	*Yurigwangmyeong*	Yurimyeong (BC 19–AD 18)
R03	AD 28	*Daemu*	Daemushin (18–44)
R04	68	*Mobon*	Taejo (53–146)
R05	73	*Shinmyeong*	Taejo (53–146)
R06	391	*Yeongrak*	Gwanggaeto (391–412)
R07	407	*Geonsi*	Later Yan dynasty (384–407)
R08	519	*Anjang*	Anjang (519–531)
R09	531	*Daejang*	Anwon (531–545)

2.2 Calendar Date

We subdivided the calendar date category into three classes: leap months and cyclic days with and without specific day numbers. A cyclic day is a sexagenary cycle assigned to a day in the Chinese calendar, and the cycle is composed of a combination of 10 heavenly stems and 12 earthly branches. Table 2 summarizes the calendar dates recorded in the Goguri annal, where columns 1 and 2 are the sequential number (no.) starting with the letter C and the class of the calendar date. Classes I, II, and III are the leap month, cyclic day without, and cyclic day with a specific day number, respectively. If the record of the calendar date denotes the occurrence of a solar eclipse, we mark an asterisk in the sequential number. Columns 3, 4, 5, and 6 represent the year, month, day, and cyclic day of the lunisolar calendar, respectively. In this study, we express the months in Arabic or ordinal numbers for the lunisolar calendar date to distinguish them from the Julian calendar dates. In addition, the number 12 has been added to the leap lunar month. For example, the month of 21 in No. C01 indicates the leap ninth month. If the record states "on the last day", we denote "29/30" in column 5. It is well known that the length of a month is 29 or 30 days in the lunisolar calendar. If the length is 29 days, it is called a *So* (small) month, else, it is called a *Dae* (large) month (Ahn & Mihn 2014). The cyclic day is expressed in an Arabic number starting with the symbol #, following the work of Lee et al. (2012). For example, the cyclic day #43 represents a *Byeongoh* (*Bingwu* in Chinese pronunciation) day among the 60 cyclic days. The month or cyclic day given in the parentheses in column 4 or 6, respectively, indicates the

Table 2. Summary of the calendar date records from the Goguri annal (Continued on the next page)

No.[1]	Class	Year	Month	Day	Cyclic day	Kingdom[2]	Note[3]
C01	I	AD 537	21				O
C02		AD 540	17				O
C03*	II	AD 73	5	29/30	#55	B	O (30)
C04*		AD 124	9	29/30	#57	S, G	O (30)
C05		AD 137	8		#37	B	O (25)
C06*		AD 141	9	29/30	#48	S	O (30)
C07*		AD 149	4	29/30	#04	G	O (30)
C08*		AD 170	3	29/30	#03	B	O (30)
C09*		AD 178	10	29/30	#13	G	O (30)
C10		AD 182	3		#51	G	X
C11		AD 186	4		#52	G	O (22)
C12*		AD 186	5	29/30	#29	S, G	O (30)
C13*		AD 194	6	29/30	#06 (#42)	S	X
C14*		AD 212	6	29/30	#27	B	O (29)
C15*		AD 219	2	29/30	#49	G	O (30)
C16*		AD 221	6	29/30	#05	B	O (29)
C17*		AD 222	11	29/30	#57	B	O (30)
C18		AD 249	1		#31	B	O (05)
C19		AD 331	2		#51		O (23)
C20		AD 419	1		#35	B	O (07)
C21		AD 478	2		#36		O (21)
C22	III	AD 22	9	1	#45		X (#21)
C23*		AD 127	7	1	#11	S	O
C24*		AD 166	1	1	#48 (#28)	S	X (#28)
C25*		AD 189	4	1	#43	B	O
C26*		AD 193	1	1	#51	S	O
C27*		AD 200	9	1	#07	S	O
C28*		AD 201	3 (2)	1	#04	S	X
C29*		AD 273	7	1	#34	G	O
C30*		AD 308	1	1	#13 (#43)	B	X (#43)
C31*		AD 325	11	1	#30		O
C32*		AD 331	7 (3)	1	#59		X
C33*		AD 335	10	1	#32	B	O
C34		AD 407	1 (2)	1	#38		X
C35*		AD 407	7	1	#35		O
C36*		AD 419	11	1	#24	B	O
C37*		AD 440	4	1	#55	B	O
C38*		AD 468	10	1	#10	B	O
C39*		AD 478	3	1	#46	B	O
C40		AD 519	1	1	#19		X (#18)
C41		AD 519	2	1	#48		O
C42		AD 519	3	1	#18		X (#17)
C43*		AD 520	1	1	#13		X (#12)
C44		AD 521	1	1	#07		O
C45		AD 522	1	1	#31		O
C46*		AD 522	5	1	#29		O
C47		AD 523	1	1	#25		O
C48*		AD 523	11	1	#20		O
C49		AD 524	1	1	#49		X (#19)
C50		AD 525	1	1	#43		O
C51		AD 525	10 (9)	12	#51		X
C52		AD 525	11	1	#39		O
C53		AD 527	1	1	#02		O
C54		AD 528	1	1	#56		O
C55		AD 529	1	1	#50		O
C56		AD 529	8	7	#53		O
C57		AD 530	1	1	#15		X (#14)
C58		AD 530	10	1	#40		O
C59		AD 530	12	1	#39		O
C60		AD 531	1	1	#09		O
C61		AD 532	1	1	#03		O
C62		AD 533	1	1	#27		O
C63		AD 534	1	1	#31		X (#21)
C64*		AD 534	4	1	#50		O
C65		AD 535	1	1	#45		O

(**Table 2.** Continued)

No.[1]	Class	Year	Month	Day	Cyclic day	Kingdom[2]	Note[3]
C66	III	AD 536	1	1	#39		X (#40)
C67		AD 537	1	1	#34		O
C68		AD 537	21	1	#59		X (#60)
C69*		AD 538	1	1	#58		O
C70		AD 539	1	1	#52		O
C71		AD 540	1	1	#22 (#46)		X (#47)
C72*		AD 540	17	1	#14		O
C73		AD 541	1	1	#10		O
C74		AD 542	1	1	#04		X (#05)
C75		AD 543	1	1	#58		X (#59)
C76		AD 544	3	1	#21		X (#22)
C77		AD 544	7	1	#20		O
C78		AD 545	1	1	#17		O
C79		AD 545	3	1	#52 (#16)		X (#17)

[1] The asterisk indicates the calendar date from a solar eclipse record.
[2] S, G, and B stand for the Silla, Goguryeo, and Baekje kingdoms, respectively.
[3] O and X denote the matching and mismatching calendar dates, respectively, with the work of HAN02.

estimated value in this study. In column 7, the kingdoms are listed if the corresponding records exist in the Sagi; the symbols S, G, and B represent the Silla, Goguryeo, and Baekje kingdoms, respectively. If this column is blank, it indicates that the calendar date is unique and recorded only in the Goguri annal. The results of comparing with the work of Han (2002; hereafter HAN02) are given in the last column, where the symbol O denotes the matching of calendar dates with those reported in the work of HAN02 and the symbol X denotes no matching. For Class II (i.e., a cyclic day without a specific day number), we also present the day number of HAN02 in the parenthesis if there is a cyclic day in the month. For Class III (i.e., a cyclic day with a specific day number), on the other hand, we present the cyclic day of HAN02 in the parenthesis if the day shows a discrepancy with that of HAN02.

The calendar dates belong to Class I (i.e., leap month) are C01 and C02. Although neither is found in the Sagi, they show agreement with the work of HAN02. Of the 19 Class II calendar dates, 17 are in accordance with HAN02. The remaining two calendar dates show discrepancies. One is the record of the third month #51 day of the year 182 (C10) stating, “at night, a red vapor pierced the *Taemi* (*Taiwei* in Chinese pronunciation) enclosure. Its shape looked like a snake.” There is no cyclic day in the month for this date according to HAN02. The same account, including the same cyclic day, is also recorded in the Sagi. The other is the record of the sixth month #06 day of the year 194 (C13) stating, “there was a solar eclipse on the last day.” According to HAN02, the sixth month is the largest with 30 days, and the cyclic day of the 30th day is not #06 but #42, which corresponds to August 4, 194. As described in Section 3.1, there was a solar eclipse observable in Korea on this date. The same account, but for cyclic day #42, is recorded in the Sagi. Therefore, it is certain that the cyclic day of #06 is a typographical error of #42 by Chang-Wha Park or Kim (2008) because the Chinese characters for *Gi* and *Eul* (*Ji* and *Yi*, respectively, in Chinese pronunciations) in the 10 heavenly stems are very similar to each other. Further, the calendar dates of the second month #51 day of the year 331and the second month #36 day of the year 478 (C19 and C21) are not recorded in the Sagi. According to HAN02, these cyclic days correspond to the 23rd and 21st days, respectively, of the lunisolar calendar, as listed in Table 2.

The number of calendar dates for Class III is the largest (58), including 13 calendar dates recorded in the Sagi. Interestingly, the day numbers of all the Class III calendar dates are the first days, except for two cases (C51 and C56). According to our examination, 20 calendar dates show disagreement with HAN02, and these can be sub-classified into five types. The first type is the case in which the cyclic day has a one-month difference compared to the work of HAN02. In one case, the records of the Goguri annal, as well as the Goguryeo annal, state that there was a solar eclipse on the third month 1, #04 day, of the year 201 (i.e., April 21, 201) (C28). According to HAN02, the cyclic day on this date was #34 and not #04, and there was no solar eclipse on Earth. For reference, the cyclic day of one month earlier, the second month 1 of the year 201 (i.e., March 22, 201), was #04, and there was a solar eclipse observable in the Korean peninsula on this day. Another case is the record of the first month 1 of the year 407 (C34), referring to the cyclic day as #38. On this date, the Goguri annal states that the Later Yan dynasty changed its reign-name to *Geonsi*, as indicated in Table 1. Practically, the dynasty enforced the *Geonsi* reign-name in the first month 1 of the year 407, in which the cyclic day was #09. Instead, the cyclic day on the second month 1 of the year 407 was #38. The other case is the record on the

tenth month 12 of the year 525 (C51), referring to the cyclic day as #51. However, the cyclic day on one month earlier (i.e., the ninth month 12 of the year 525) is #51, according to HAN02. The second type includes cases in which the cyclic day is estimated as a typographical error in the 10 heavenly stems or 12 earthly branches, and the same error is also found in the Sagi (C24 and C30). The third type is the same as the second type, but is not recorded in the Sagi (C22, C49, and C63). The fourth type comprises three cases in which it is difficult to estimate the causes of the errors. One is the record stating "there was a solar eclipse on the first day, #59 day, of the year 331" (C32). Although Kim (2008) estimated the month to be seventh, the cyclic day on that date was #57 and there was no solar eclipse on Earth. Further, the cyclic day on the third month 1 of the year 331 (i.e., April 24, 331) was #59, but there was no solar eclipse on Earth. The remaining two cases are the records of the first month 1 of the year 540 (C71) and third month 1 of the year 545 (C79), stating the cyclic days as #22 and #52, respectively. However, they were #47 and #17, respectively, according to HAN02. If we assume that the cyclic days #22 and #52 are the typographical errors of #46 and #16, then both belong not only to second type (i.e., typographical errors between *Gi* and *Eul* in the 10 heavenly stems) but also to the last type where the cyclic day has a one-day difference compared to the work of HAN02 (i.e., C40, C42, C43, C57, C66, C68, C74, C75, and C76). Referring to the work of Xu (1992), these calendar dates also show the same differences compared to those of China at those times. Regarding this type, it is noteworthy to pay attention to the solar eclipse record of the first month 1 of the year 520 (C43), which is not included in the Sagi. According to the Chinese chronicles, the cyclic day on the first month 1 of the year 520 is #12 day in the Beiwei (AD 386–534) and Xiaoliang (AD 502–557) dynasties. In contrast, the chronicles of the former and latter dynasties indicate that a solar eclipse occurred on #12 (i.e., February 4, 520) and #13 days (i.e., February 5, 520 or first month 2 of the year 520), respectively. However, according to modern computation, there was a solar eclipse observable in Korea and China on February 5, 520. Considering the fact that the record of the Beiwei dynasty does not agree with modern computation and that there were no solar eclipse records on the second lunar day, it can be inferred that the record of the Goguri annal, the cyclic day on the first month 1 of the year 520 was #13, is the most plausible.

3. CELESTIAL PHENOMENA

Table 3 summarizes the celestial phenomena records from the Goguri annal. In the table, columns 1 and 2 are the sequential number (no.) starting with the letter P and the category of celestial phenomena: SE, TR, CO, DA, ME, and OT, which represent the solar eclipse, *Beom* (literally trespass), comet, daylight appearance of Venus, meteor/meteorite, and other, respectively. Columns 3, 4, and 5 represent the year, month, and day, respectively. The values given in the parentheses in columns 4 or 5 are the ones that have been estimated in this study. In column 6, the kingdoms are listed if the corresponding records exist in the Sagi. The meanings of the symbols S, G, and B are the same as those in Table 2. When the Goguri annal states that a phenomenon occurred in the Silla or Baekje kingdoms, not Goguryeo, we mark it as S* or B*. According to our examination, all these cases have been recorded in each annal of the Sagi. In addition, we use the symbol C if the phenomenon has been recorded in the Chinese chronicles. If this column is blank, it means that the phenomenon is unique and recorded only in the Goguri annal. For information in the last column, refer to the explanation provided in each corresponding subsection.

In the modern calculations of celestial phenomena, we used the astronomical algorithms of Meeus (1998) and the DE441 ephemeris of Park et al. (2021). For the difference value between the terrestrial and universal times, ΔT, we employed the polynomial formula given by Morrison et al. (2021). To calculate the magnitude of a solar eclipse in a given circumstance, we utilized Besselian elements, as done in the work of Lee (2008). In addition, we used the formula given by Hilton (2005) to calculate the visual magnitude of Venus. We referred to the work of Kim (2020) for identifying the stars in the records with those in the modern catalog. Finally, all times have been given in Korean standard time (i.e., UT+9 h), unless otherwise mentioned.

3.1 Solar Eclipse

A total of 37 solar eclipses were recorded in the Goguri annal, including five eclipses that did not occur on Earth (nos. P21, P22, P23, P25, and P26), denoted by the symbol N in the last column. In this column, the symbols O and U indicate that an eclipse was observable and unobservable, respectively, in East Asia. Of the 37 solar eclipses, nine are not recorded in the Sagi (nos. P24, P25, P27, and P32–P37). In other words, 28 solar eclipses are also recorded in the annals of the Sagi, including eight in the Goguryeo annal (nos. P02, P03, P06, P07, P10, P11, P18, and P22). In contrast, two solar eclipses recorded in the Goguryeo annal of the Sagi, in the third month of the year 114 and in the fifth month of the year 158, are omitted in the Goguri annal.

Table 3. Summary of the celestial phenomenon records from the Goguri annal

No.	Category[1)]	Year	Month	Day	Kingdom[2)]	Note[3)]
P01	SE	73	Jul	23	B, C	O
P02		116	(Apr)	(1)	G, C	O
P03		124	Oct	25	S, G, C	O
P04		127	Aug	25	S, C	O
P05		141	Nov	16	S, C	O
P06		149	Jun	23	G, C	O
P07		165	(Feb)	(28)	G, C	O
P08		166	Feb	18	S, C	O
P09		170	May	3	B, C	U?
P10		178	Nov	27	G, C	O
P11		186	Jul	4	S, G, C	O
P12		189	May	3	B, C	O
P13		193	Feb	19	S, C	O
P14		194	Aug	4	S, C	O
P15		200	Sep	26	S*, C	O
P16		201	(Mar)	(22)	S*, C	O
P17		212	Aug	14	B, C	O
P18		219	Apr	2	G, C	O
P19		221	Aug	5	B, C	O
P20		223	Jan	19	B, C	O
P21		256	Dec	4	S*, C	N
P22		273	Aug	1	G, C	N
P23		308	Feb	8	B*, C	N
P24		325	Dec	22	C	O
P25		331	(Apr)	(24)	C	N
P26		335	Nov	2	B*, C	N
P27		407	Aug	19	C	O
P28		419	Dec	3	B, C	O
P29		440	May	17	B, C	O
P30		468	Nov	1	B, C	O
P31		478	Apr	19	B, C	U
P32		520	Feb	5	C	O
P33		522	Jun	10	C	O
P34		523	Nov	23	C	O
P35		534	Apr	29	C	O
P36		538	Feb	15	C?	U?
P37		540	Jun	20	C	O
P38	TR	137	Sep	27	B*, C	Ma/Na
P39		205	7		S*, B	Mo/Ve
P40		249	Feb	5	B*, C	Mo/Ve
P41		484	3		S	Mo/Sa
P42	CO	128	8		S*	
P43		149	8		S, C	
P44		186	10		B*	
P45		191	9		S, B, C	
P46		217	10		G, C?	
P47		269	9		B*, C	
P48		302	4		B*, C	
P49		315	11		G?	
P50		383	9		G	
P51		419	Feb	17	B, C	
P52	DA	200	7		S*	
P53		224	10		B*	
P54		321	2		B?	
P55	ME	120	2		S*	
P56		278	1			
P57		316	1		B*	
P58		333	5		B*, C?	
P59		336	2		G?	
P60	OT	149	5		G	N
P61		182	3	#51	G	
P62		186	May	28	G, C	
P63		246	10		S*	
P64		534	7		B?, C?	

[1)] SE, TR, CO, DA, ME, and OT represent the solar eclipse, trespass, comet, daylight appearance of Venus, meteor/meteorite, and other, respectively.
[2)] S, G, and B are the same as those in Table 2. S* and B* represent the phenomena occurred in the Silla and Baekje kingdoms, respectively. C stand for the Chinese chronicle. The question mark indicates the case showing a minor difference with the record of the Goguri annal.
[3)] For details, refer to the text.

Some notable characteristics of the solar eclipse category are as follows: First, the record of the year 116 (no. P02) simply states that a solar eclipse occurred in the third month, without referring to either the day number or the cyclic day. Similarly, the Sagi also does not contain the day number and cyclic day. According to the work of HAN02, the third month 1 in the year 116 is March 31, 116 but a solar eclipse occurred on April 1, 116, as listed in Table 3. This discrepancy can be solved by assuming that the length of the second month in the year 116 is 30 days, and not 29 days in the work of HAN02, although it cannot exclude the possibility that the day number and the cyclic day were not recorded because the solar eclipse occurred on the second lunar day. In addition, this solar eclipse is also recorded in the Chinese chronicle but it is the eclipse that the historiographer "heard," not "observed," from Liaodong region (Park & La 1994; Yang 2019). As shown in Fig. 1(a), this eclipse was unobservable in China but observable in

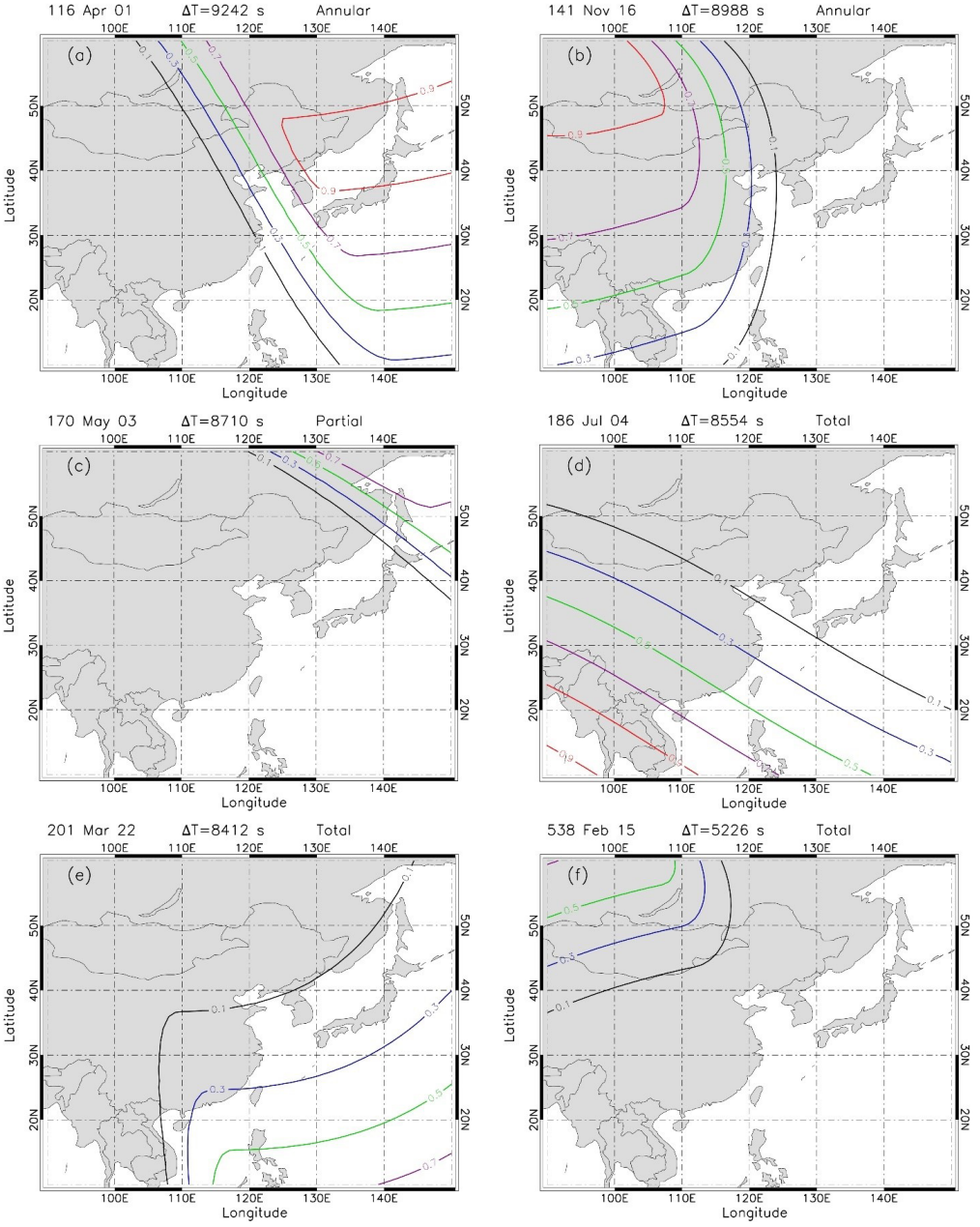

Fig. 1. Maps of the solar eclipses that occurred on (a) April 1, 116, (b) November 16, 141, (c) May 3, 170, (d) July 4, 186, (e) March 22, 201, and (f) February 15, 538.

the Goguryeo kingdom. Similar to other solar eclipses, our eclipse maps are slightly different from the works of Park & La (1994) and Lee et al. (2011), primarily due to the different ΔT values. The record of the year 165 (no. P07) states that a solar eclipse occurred on the last day of the first month without referring to the cyclic day. According to HAN02, it was a large month, corresponding to February 28, 165. At that time, a solar eclipse was observable in Korea and China. In addition, the dates for the records of the years 201, 331, and 520 (nos. P16, P25, and P32) are March 22, 201, April 24, 331, and February 5, 520, respectively, as discussed in Section 2.2. Solar eclipses did occur on these dates, although the magnitude of the eclipse on March 22, 201 was small in Korea and China (refer to Fig. 1(e)).

Second, the solar eclipse that occurred on November 16, 141 (no. P05) was certainly and marginally observable in China and the Goguryeo kingdom, respectively, but was unobservable in the Silla kingdom (Fig. 1(b)), unlike in the record in the Sagi. The solar eclipse on May 3, 170 (no. P09) was unobservable in the Baekje kingdom and China, but could be observed in the Goguryeo kingdom, which had a large territory, as depicted in Fig. 1(c). On the other hand, the solar eclipse on July 4, 186 (no. P11) was practically impossible to observe in the Silla and Goguryeo kingdoms because the greatest eclipse magnitude was much smaller than that on March 22, 201, but was observable in China (Fig. 1(d)). With regards to the solar eclipse in the year 538, the Chinese chronicle says that there was a solar eclipse on the first day, #38 day, of the first month in the Dongwei (AD 534–550) dynasty. However, the cyclic day #38 might be a typographical error of #58 (i.e., the second type in the Class III calendar date). If so, the corresponding date is February 15, 538, which is similar to the record in the Goguri annal (no. P36), which mentions the occurrence of a solar eclipse but this was almost unobservable in Korea and China (Fig. 1(f)). On the other hand, no solar eclipse occurred on April 19, 478 (no. P31), but occurred on one day earlier, on April 18, 478. However, this eclipse was visible in South America and the South Pacific Ocean.

Third, the years 256, 273, 308, 331, and 335 (no. P21-23, P25, and P26) have records of solar eclipses that did not occur on Earth. A possible explanation of this is that they are "predicted" eclipses through the calendrical calculations at that time, not observed ones. Although it is a later period record, the Silla annal of the Sagi of the fifth month 1 of the year 801 mentions that a solar eclipse was expected but did not occur, which implies that the astronomer of the Silla kingdom had the required astronomical knowledge to predict the solar eclipse, although the knowledge was inaccurate. An alternative explanation is that these were copied from the records of the Chinese chronicles by Chang-Wha Park, as suggested by Stephenson (2013) for the solar eclipse records in the Sagi. However, this suggestion cannot explain why the Chinese chronicles also contain solar eclipse records that did not occur on Earth. Moreover, it is difficult to explain the reason that the cyclic day of the first month 1 of the year 538 is correct in the Goguri annal but incorrect in the Chinese chronicle, as mentioned above. Consequently, it is difficult to conclude that Chang-Hwa Park copied the solar eclipse records from the Chinese chronicles, although almost all records of the Goguri annal are contained in the chronicles.

3.2 Trespass

In this study, we considered the *Beom* (literally, trespass) and *Seup* (literally, sudden attack) records in the trespass category. According to the *Seoungwan-Ji* (Treatise on the Royal Astronomical Bureau) published in 1818, while the latter event is not explained, the former is described as an event in which the rays of two celestial bodies reach within one *Chon* (*Cun* in Chinese pronunciation), i.e., 0.1° with respect to each other. In the last column in Table 3, we present the celestial bodies involved in the events: Ma is Mars, Mo is the Moon, Na is the *Namdu* (*Nondou* in Chinese pronunciation) constellation (ϕ, λ, μ, σ, τ, and ζ Sgr), Sa is Saturn, and Ve is Venus. Of the four events in the trespass category, the Goguri annal states that the phenomena that occurred in the years 137 and 249 (nos. P38 and P40), and in 205 (no. P39) were observed in the Baekje and Silla kingdoms, respectively. All trespass category records are the same as those in the Sagi, including the fact that the records of the years 205 and 484 (no. P41) mention only the month, i.e., they do not mention the day number and the cyclic day, and the record of the year 249 uses the term *Seup*, not *Beom*.

To verify the celestial phenomena of the trespass category, we first assumed the locations of the observers as the capitals of the kingdoms, Gyeongju (longitude 129.23°E and latitude 35.87°N) and Wiryeseong (longitude 126.98°E and latitude 37.56°N) for the Silla and Baekje kingdoms, respectively, and Pyeongyang (longitude 125.75°E and latitude 39.03°N) for the Goguryeo kingdom, although it has been the capital of the kingdom since 427. We then calculated the angular separation (AS) at intervals of 1 min under the condition that the altitudes of both celestial bodies were above the horizon from sunset on the day of the record to sunrise on the next day, and then obtained the minimum separation between them. Although it is unknown for the Three Kingdoms period, the day was not changed for the astronomical phenomenon observed after

midnight during the Joseon dynasty (Ahn & Park 2004). These results are summarized in Table 4, where columns 1 and 2 are the date and the celestial bodies involved in the event, respectively. Columns 3 and 4 list the sunset time (SS) on the date given in column 1 and the sunrise time (SR) on the next day, which is expressed as the time added to 24 h. Column 5 presents the minimum AS between the celestial bodies and the last column is the observation location, where G is Gyeongju, W is Wiryeseong, and P is Pyeongyang.

According to our calculations using the astronomical algorithms of Meeus (1998) and the DE441 ephemeris of Park et al. (2021), Mars was the closest to λ Sgr among the six stars of the *Namdu* constellation on September 27, 137, and the AS between them was 0.23°, as indicated in Table 4. In contrast, the Moon and Venus were not observable simultaneously from sunset on February 5, 249 to sunrise on the next day. Regarding the records of the years 205 and 484 (i.e., records that mention only the month), we performed calculations for the dates from August 3–September 1, 205 and April 12–May 11, 484, respectively, referring to the work of HAN02. In the latter case, the Moon and Saturn were closest to each other on April 16, 484, with an AS of 0.92°. However, in the former case, the minimum AS between the Moon and Venus was 6.91° on August 5, 205 whereas that between the Moon and Jupiter was 3.25° on August 12, 205. For reference, the average angular distance for the trespass category was approximately 1° in the records of the Josen dynasty (Ahn et al. 2010; Lee 2023).

3.3 Comet

The characteristics of the comet records in the Goguri annal can be summarized as follows: (i) four among the 10 records are events observed in the other kingdoms: one (no. P42) and three (nos. P44, P47, and P48) in the Silla and Baekje kingdoms, respectively. (ii) According to the catalog by Kronk (1999), all comets were not observed in other countries except for China. Furthermore, the comets that appeared in the years 128, 186, 315, and 383 were not observed in China. On the other hand, it seems that the comet that appeared in the year 217 was observed in China, although its record states that the observation period was in the winter, while the Goguri annal mentions that it was observed in the tenth month. (iii) Strangely, there are no records of the Halley's comet. The same is the case for the records of the Sagi, which cover approximately 970 years (Lee et al. 2014). In contrast, interesting records include observations for the years 302 and 315. The former record states that a comet was observed during daylight. Hasegawa (1980) suggested that this comet is presumably a member of the Kreutz sungazing comets. However, it is known that the Halley's comet (which is not a member of the Kreutz sungazing comets) was also sufficiently bright to be observed during daylight in its apparition of 1222 (Choi et al. 2018). The latter record states the observation period as the eleventh month, in contrast to the record of the Goguryeo annal which states it to be the eighth month. As this comet has not been reported in other countries, it is difficult to determine which annal record is correct.

3.4 Daylight Appearance of Venus

Of the three records on the appearance of Venus during daytime, two records of the years 200 and 224 (nos. P52 and P53) are the events observed in the Silla and Baekje kingdoms, respectively. The remaining record of the year 321 (no. P54), stating that the event occurred in spring in the second month, is unique which is found neither in the Sagi nor in the Chinese chronicles. On the other hand, the record of the Baekje annal of the Sagi for the year 321 states that Venus was seen during daylight in autumn in the seventh month, and that there was an insect plague on the grains in the southern province. It is worth noting that the record of the Goguri annal for the second month of the year 321 also not only mentions the daylight appearance of Venus, but also the same insect plague. According to HAN02, the seventh month in 200, tenth month in 224, and second month in 321 correspond to the periods of July 29–August 27, 200, October 30–November 28, 224, and March 15–April 13, 321, respectively. We calculated the maximum apparent magnitude of Venus, including its elongation, during each period and found that Venus was the brightest

Table 4. Summary of the AS for the trespass event recorded in the Goguri annal

Date (year month day)	Celestial bodies	SS (h:min)	SR (h:min)	AS (°)	Note[1)]
137 Sep 27	Mars/λ Sgr	18:24	30:24	0.23	W
205 Aug 5	Moon/Venus	19:24	29:30	6.91	G
249 Feb 5	Moon/Venus	18:03	31:35	NE[2)]	W
484 Apr 16	Moon/Saturn	19:15	29.55	0.92	P

[1)] G, W, and P stand for Gyeongju, Wiryeseong, and Pyeongyang, respectively.
[2)] NE represents not measurable.
SS, sunset time; SR, sunrise time; AS, angular separation. For details, refer to the text.

at the ends of each month of the years 220 and 224; its magnitudes were –3.9 and –4.7 on August 27, 200 and November 28, 224, respectively, and its elongations at those times were 35.1° and 46.4°, respectively. On the contrary, Venus was the brightest at the beginning of the month in the year 321, with its magnitude and elongation being –4.4 and 46.1°, respectively. Hence, the average values of the maximum apparent magnitude and elongation are –4.3 and 42.5°, respectively. For reference, the seventh month in 327 (i.e., the observation period of the Sagi) corresponds to the period from August 10–September 7, 321, and Venus was the brightest on September 7 with a magnitude of –3.9. However, it was impossible to observe Venus during daytime on this date because it was very close to the Sun; the solar elongation was 7.9°. According to Lee (2017), the average magnitude and solar elongation were –4.5 ± 0.3 and 39.8 ± 7.8° for the events of the daylight appearance of Venus recorded in the *Goryeosa* (History of the Goryeo Dynasty; AD 918–1392). Compared to the value obtained by Lee (2017), the magnitude of Venus on August 27, 200 is slightly faint to be observed during daylight. However, it is known that the limiting magnitude of a celestial body to be seen during broad daylight with the naked eye is approximately –3.3 (Weaver 1947).

3.5 Meteor/Meteorite

Similar to other astronomical phenomena, the Goguri annal contains meteor/meteorite records observed in the Silla and Baekje kingdoms: Silla for the event in AD 120 (no. P55) and Baekje for the events of AD 316 and 333 (nos. P57 and P58). Because the Goguri annal and Sagi state that a large star fell onto the west of the Wolseong area on the second month in the year 120, we can infer with certainty that it was a meteorite. On the other hand, the record for the year 316 in the Sagi states that a large star "flowed out" (therefore, meteor) toward the west and that in the Goguri annal states that a large star "fell onto" (therefore, meteorite) the west border area. The record for the year 333 states that a star fell onto the palace in the Baekje kingdom in the fifth month. Interestingly, the *Jinshu* (History of the Jin Dynasty in China) also states that a star fell in the same month, i.e., the fifth month in the year 333, but onto Fexiang, a district of the southern Hebei province. The record of the year 336 (P59) has a difference in the observation month in both annals. While the Goguri annal states that a large star flowed out toward northwest in the "second" month, the Goguryeo annal states it to be the "third" month. The meteorite record for the first month of the year 278 (no. P56), which appears only in the Goguri annal, is related to astrological content: A noble child will be born because a *Cheonrang* (maybe a typo of *Cheongu*; *Tiangou* in Chinese pronunciation) star fell onto the palace.

3.6 Other

The record of the fifth month of the year 149 (no. P60) states that the *Ohseong* (literally, five planets: Mercury, Venus, Mars, Jupiter, and Saturn) were gathered in the eastern area. The fifth month of the year 149 corresponds to June 24–July 22, during which no such event occurred, as denoted by the symbol N in the last column. The record of the third month of the year 182 (no. P61) states that a red vapor pierced the *Taemi* enclosure and it looked like a snake, as mentioned in Section 2.2. The record of the tenth month in 246 (no. P63) states that a white vapor that looked like a hemp cloth was observed in the northeast. Both records are estimated to be auroral or zodiacal light events, and the latter record is the event observed in the Silla kingdom, as denoted by the symbol S* in the sixth column. The records of May 28, 186 (no. P62) and the seventh month of the year 534 (no. P64) are the *Su* (*Shou* in Chinese pronunciation) and *Ip* (*Ru* in Chinese pronunciation) events, respectively. In the *Joseonwangjosillok* (The Veritable Records of the Joseon Dynasty), these events are explained as follows: If a celestial body entered a constellation, it is a *Su* (literally, guard) event if the body stayed in it for a long time, and an *Ip* (literally, entry) event if the body came out from it. The former record of May 28, 186 states that Mars guarded the *Sim* (*Xin* in Chinese pronunciation) constellation (σ, α, and τ Sco). Fig. 2 shows the orbital path of Mars in the equatorial coordinates before and after May 28, 186. As shown in the figure, the location of Mars on May 28, 186 was between the positions on the dates started its retrograde and prograde motions (i.e., April 13 and June 20, respectively). The latter record of the seventh month in 534 states that Mars entered the *Namdu* constellation. The dates of the seventh month in 534 correspond to July 26–August 24, 534. A similar event has been recorded for the fourth month #04 day of 534 (i.e., May 13, 534) in the Baekje annal of the Sagi and the *Liangshu* (History of the Liang Dynasty in China), and the Sagi and *Liangshu* state that Mars "trespassed" (not "entered") the *Namdu* constellation. Fig. 3 shows the orbital path of Mars in the equatorial coordinates from April 1–September 1, 534. It can be said that Mars entered the *Namdu* constellation and left it during the seventh month in 534, i.e., between July 26 and August 24 (refer to points 5 and 6, respectively, in Fig. 3). In contrast, the event of Mars trespassing against the *Namdu* constellation did not occur on May 13, 534 (refer to point 2 in Fig. 3), unlike the

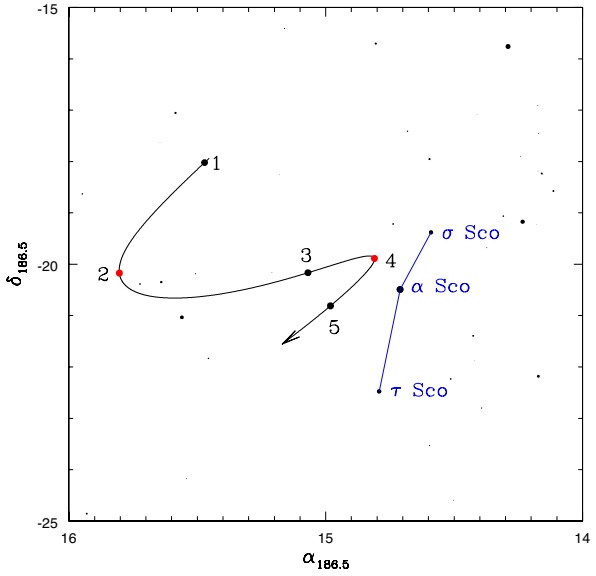

Fig. 2. Orbital path of Mars in the equatorial coordinates before and after May 28, 186. The positions marked by the Arabic numbers are (1) March 13, (2) April 13, retrograde motion, (3) May 28, (4) June 20, prograde motion, and (5) July 10. The blue solid line is the *Sim* constellation.

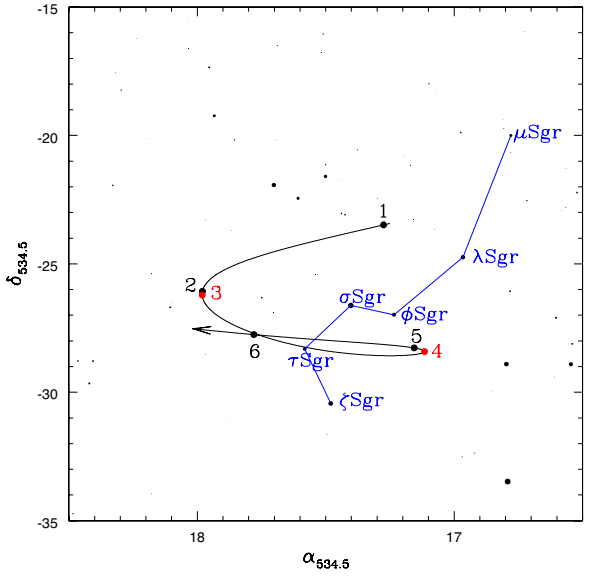

Fig. 3. Orbital path of Mars in the equatorial coordinates before and after May 13, 534. The positions marked by the Arabic numbers are (1) April 1, (2) May 13, (3) May 15, retrograde motion, (4) July 17, prograde motion, (5) July 26, and (6) August 24. The blue solid line is the *Namdu* constellation.

records of the Sagi and *Liangshu*. Instead, according to our calculations, Mars was the closest to τ Sgr on August 18, 534 with an angular separation of 0.40°. Therefore, the record of the Goguri annal is more accurate than that of the Sagi or *Liangshu*.

4. SUMMARY AND CONCLUSION

Chang-Hwa Park wrote the history of the Goguryeo kingdom during the Three Kingdoms period, which has been referred to as the Goguri annal in this study. Similar to the *Hwarangsegi*, another of his works, the authenticity of the annal is disputed. In contrast to political and historical events, certain celestial phenomena are reproducible by performing modern astronomical calculations. Hence, we have investigated the astronomical records of the Goguri annal to verify its authenticity. We have extracted the astronomical records and classified them into eight categories: reign-name, calendar day, solar eclipse, trespass, comet, daylight appearance of Venus, meteor/meteorite, and other. We have then clustered the categories into two groups, calendrical data and celestial phenomena, and analyzed each group by comparing the records of the Sagi and the Chinese chronicles with the results of modern calculations, wherever possible. Our findings are as follows:

- We have found that the Goguri annal contains astronomical records observed not only in the Goguryeo but also in the Silla and Baekje kingdoms, which are different from the records of the Sagi.
- We have grouped the reign-name and calendar date categories into the calendrical data. The former category shows the largest difference not only with the records of the Sagi but also with the currently known facts. More specifically, the Goguri annal states the reign-names using the names of kings in the Goguryeo annal of the Sagi such as *Dongmyeong*, *Yurigwangmyeong*, and *Daemu*. The latter category contains many records that are not included in the Sagi. In addition, some records imply the possibility of the errors in the work of HAN02 in terms of the cyclic day of the first day in a lunar month.
- The celestial phenomena group includes the following categories: solar eclipse, trespass, comet, daylight appearance of Venus, meteor/meteorite, and other. Although the Goguri annal contains the solar eclipse events not recorded in the Sagi, all of these events are recorded in the Chinese chronicles, including not only unobservable events in the Goguryeo kingdom but also those that did not occur on Earth. Therefore, the possibility that Chang-Hwa Park copied the solar eclipse records from the Chinese literature cannot be excluded. However, it is worth noting that the solar eclipse record of the Goguri annal on the first month 1, #13 day, of the year 520 is more reasonable than the Chinese records, as discussed in Section 3.1. In addition, it is remarkable that some records of the

trespass, comet, and daylight appearance of Venus categories are not included in the Chinese chronicles, although all are contained in the Sagi. Most notable are the records in the meteor/meteorite category, although the events are not reproducible. The record of the year 336 shows a difference of one month in the observation compared to the Sagi; the second and third months in the Goguri annal and Sagi, respectively. Furthermore, a meteorite falling event in the year 278 is recorded only in the Goguri annal. In the other category, it is also worth noting that the record of the seventh month in 534, stating that Mars entered the *Namdu* constellation, is in good agreement with the results of modern calculations. In contrast, similar records of the Sagi and *Liangshu*, stating that Mars trespassed the *Namdu* constellation on May 13, 534 (i.e., the fourth month #04 day of the year 534), show a discrepancy with modern computations.

In conclusion, we believe that it is difficult to affirm that the Goguri annal is a pseudograph, at least in terms of its astronomical records, although the majority of them are included in the Sagi and the Chinese chronicles. In particular, we believe that it is noteworthy to pay attention to the solar eclipse record on the first month 1 of the year 520 and the entry record on the seventh month of the year 534, which show good agreement with modern calculations, and to the meteorite record on the first month of the year 278, which was neither recorded in the Sagi nor the Chinese chronicles.

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