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Meteorite falls in China and some related human casualty events

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Abstract–Statistics of witnessed and recovered meteorite falls found in Chinese historical texts for the period from 700 B.C. to A.D. 1920 are presented. Several notable features can be seen in the binned distribution as a function of time. An apparent decrease in the number of meteorite reports in the 18th century is observed. An excess of observed meteorite falls in the period from 1840 to 1880 seems to correspond to a similar excess in European data. A χ^2 probability test suggests that the association between the two data sets are real. Records of human casualties and structural damage resulting from meteorite falls are also given. A calculation based on the number of casualty events in the Chinese meteorite records suggests that the probability of a meteorite striking a human is far greater than previous estimates. However, it is difficult to verify the accuracy of the reported casualty events.

INTRODUCTION

Owing to the random nature of the time of appearance of spectacular fireballs, much of our data on these objects comes from informal reports made by those who happen to be outdoors at the time. In today's overcrowded and light-polluted urban areas, coupled with urban dwellers spending much of their time indoors (particularly at night), the chance of witnessing and pinpointing the fall of a subsequently recovered meteorite during a lifetime is small. Even under the best of conditions, only a small number of meteorites are recovered immediately after the fall. Based upon witnessed and recovered meteorite falls in Japan, India, Western Europe and the United States in the period from 1840 to 1939, Brown (1960, 1961) deduced a range of rates between 0.32 and 1.1 recovered falls/year/10^6km^2 for the mass range between 50 g and 6000 kg. Hughes (1980) estimated the average rate of meteorites arriving on Earth to be about 90 falls/year/10^6km^2 in the mass range from 100 g to 1000 kg. Halliday *et al.* (1989) put the fall rate of meteorites having masses greater than 100 g to be about 58/year/10^6km^2.

Looking at a map of the world distribution of recovered meteorites, one can see that many parts of the globe are blank (Sears, 1978; Hughes, 1981). Taking away those uninhabited and sparsely populated areas, we are still left with large blank areas. The absence of meteorites in these areas can be due either to an incomplete sampling of available fall records or to a lack of public awareness of these objects. The high concentration of finds in North America probably reflects the public interest in meteorites there. The obvious ways to fill in some of these blank spots are to educate the public in recognizing meteorites and to encourage them to report any sightings or finds to a museum or an equivalent institution. Another way is to carry out a thorough search for any documented falls.

In the present paper, we use the Chinese histories to investigate two problems associated with meteorite falls. In the first half of this paper, we analyze all reported meteorite falls for the frequency of occurrence in China between about 700 B.C. and A.D. 1920. In the latter half of the paper, we examine the circumstances relating to several reports of meteorite falls that resulted in human casualties and estimate the probability of being hit by a meteorite.

SOURCE AND BACKGROUND

The earliest meteorite fall record from China is found in the chronicle *Ch'un-ch'iu (Spring and Autumn Annals)*, a work attributed to Confucius (551–479 B.C.). The entry for December 24, 645 B.C. states that "Five stones fell in Sung (one of the states at the time)" (Stephenson and Yau, 1992). From that date to the beginning of the present century, more than 300 records of recovered witnessed meteorite falls can be located in Chinese histories. The number of meteorites listed under China in *Catalogue of Meteorites* by Graham *et al.* (1985) is only 35 observed falls and 32 finds for the period from about 1920 to 1980. The vast number of meteorite falls documented in Chinese historical texts prior to this date are not included.

Owing to the difficulty in gaining access to the Chinese archives on meteorites, very little has been published in this area. Biot (1848) published one of the earliest works in the West on this subject. However, all the early catalogs are rather incomplete. For the present paper, we have compiled a composite list of witnessed and recovered meteorite falls from two recent catalogues by Chen (1984) and Xuan and Xia (1988) in Chinese. We have checked the records carefully in both of these catalogs against each other and also against the original sources. All apparent mistakes, such as conflicts in the conversion of dates from the Chinese to Western calendar, have been corrected. We have excluded from the present list fireballs that did not produce a recoverable fragment on the ground.

The original sources for the meteorite records may be grouped into three categories: (1) official histories, (2) local histories, and (3) miscellaneous historical works. The official histories of a dynasty are usually compiled after it has fallen from power by the Historical Bureau of the succeeding dynasty from the central archives. They always contain a chapter known as the Astronomical Treatise where records of the court astronomers are preserved (Needham, 1959). These records cover all sky phenomena observable with the naked eye and have been proven to be highly reliable. They have been applied to studies of a wide range of topics in astronomy. For example, observations of comets have been used to determine the long-term motion of comet Halley (Yeomans and Kiang, 1981; Stephenson and Yau, 1985) and recently, comet P/Swift-Tuttle (Yau *et al.*, 1994). Records of solar and lunar eclipses have been used successfully to obtain the rate of Earth's rotation in the past (Stephenson and Morrison, 1984). Also, "guest star" records have helped astronomers to identify the celestial positions of past supernova explosions (Clark and Stephenson, 1977).

The second category of sources comprises histories at the local administrative levels, from provinces down to the districts. A typical district in China is roughly 1500 km^2; a province is typically 200,000 km^2. Local histories were usually compiled by a team of local government officials and eminent local scholars from local registers. Local histories are also known as local gazetteers, because they originated from local guides that included maps and texts introducing the general natural features of a region. However, by about A.D. 1400, they had evolved to become comprehensive regional histories. The centuries that followed saw a rise in their popularity. As a result, about 7500 different local histories are extant today in major libraries around the world (Chen, 1965).

These constitute the bulk of the astronomical records after A.D. 1400. All of the local histories followed a somewhat standard format and included chapters on local population, customs, economy, produce, construction, schools, dignitaries, historical sites and natural disasters. A chapter was always devoted to ominous and unusual events seen in the district. It is within these chapters that we expect to find any records concerning astronomical events, which were usually reported by common citizens. Although these reports are less technical, they still present a good source for astronomical observations. For example, sunspot sightings found in the local histories have been used as indicators of the solar activity during the Maunder Minimum period 1645–1715 (Yau, 1988).

The third category of sources is the various historical works. These include chronicles, encyclopedia, diaries, memoirs and private histories. Most texts were compiled by scholars of the time based on their own collections or private libraries and are a good source of material supplementing both the official and local histories. However, very few meteorite fall records come from this category.

DATA ANALYSIS

Frequency Distribution

The frequency of witnessed and recovered meteorite falls in China per decade from 700 B.C. to A.D. 1920 is shown in Fig. 1a. The histogram shows a low frequency of falls before about A.D. 1300 and then a steep rise in the numbers. Before about A.D. 1300, nearly all of the records come from the official histories. As mentioned earlier, the official histories included mostly astronomical records derived from the daily reports prepared by court astronomers with only a few reports from outside the capital. From early times, court astronomers were appointed by the throne to keep a constant watch day and night for any signs of ominous portents that might appear in the sky. The observations were carried out at the imperial observatory in the capital city of the time. As meteorites fall randomly, the observations were made at one place and reports were mostly gathered from the local area, few meteorites would be recorded. This factor likely explains the low frequency of falls for the pre-A.D. 1300 period. The increase in the number of reports of meteorite falls after about A.D. 1300 can be ascribed to the contribution of the local histories. These meteorite falls were observed locally in various regions of China. Including records from the local histories, we have a larger sample of the population of meteorites that landed on Earth.

A distinct drop in the number of meteorite falls in the 18th century can be seen in the data in Fig. 1a. For the purpose of comparing with any variations in the population that could have affected the recording of meteorite falls, the population of China for the period A.D. 2 to 1900 is plotted in Fig. 1b (data are taken from Durand, 1960). The general agreement in the trend between the meteorite fall numbers and population statistics is apparent. However, the correlation between the details of the two distributions does not appear to be strong. The dramatic decrease in the number of meteorite fall records in the 18th century is obviously not related to population changes.

In order to see the underlying distribution in detail, the post-A.D. 1300 data have been rebinned in 10-year intervals (Fig. 2a). Two main features can be seen in Fig. 2a, one centered around 1600 and the other at 1860 with an unexpected decrease in the number of reports from about 1690 to 1780. We have checked the histories for historical events during this period; there were no wars, population movements, or any other events that would have affected the long-term recovery rate. A major change of the political scene is often reflected by a short-term change in the astronomical data. For example, the dip in the 1640–1650 interval is most probably caused by the chaos preceding and following the change from the Ming Dynasty to the Ch'ing Dynasty in 1644. It appears that the number of observed meteorite falls in China during the 18th century is generally lower. Further, the prominent peak around 1860 is likely to be a genuine increase in the observed (and recorded) fall rate of meteorites.

We have performed a χ^2 test (Press *et al.*, 1992) on the binned Chinese meteorite data for the period 1750 to 1920 to see how significant the peak is around 1840–1880 (Fig. 3). We assumed a uniform distribution for this data set. That is, we expected all the bins to be equally likely, and the meteorites not to show a preference to fall in any of the bins. The mean for the data set is 6.65 meteorite falls per bin, which is the expected frequency. The analysis gives a value for $\chi^2 = 46.02$ and a probability of 1.7×10^{-4} for the distribution of Chinese meteorite data in the period 1750–1920. The small probability suggests that the observed meteorite falls are significantly different from a uniform distribution and the observed peak at 1840–1880 is probably real.

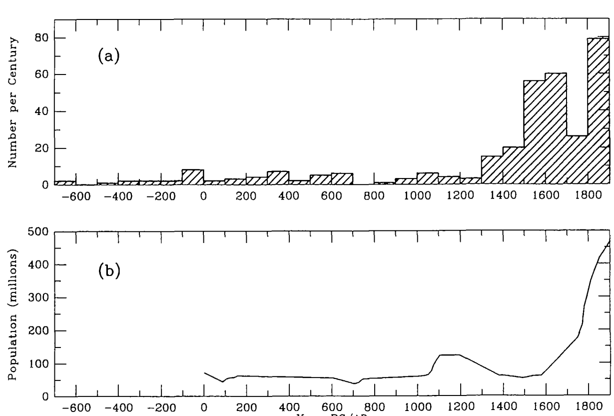

FIG. 1. (a) Frequency distribution of witnessed and recovered meteorite falls in China per century from 700 B.C. to A.D. 1900. (b) The population of China in the period from A.D. 2 to 1900. Reporting of falls increases after 1300 due to the rise of the local histories.

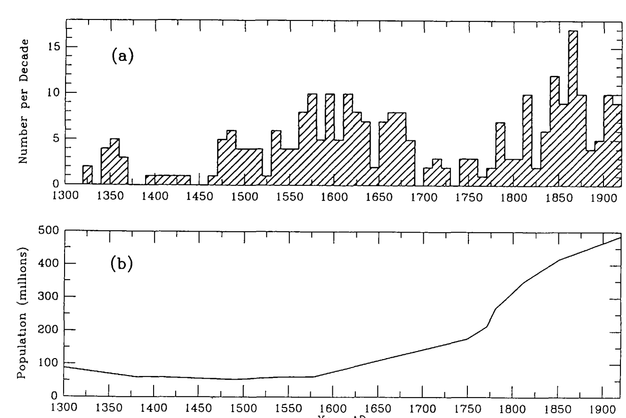

FIG. 2 (a) Frequency distribution of witnessed and recovered meteorite falls in China per decade for the period from A.D. 1300 to 1920. (b) The population of China during the same period.

The increase during the interval 1840 to 1880 is also seen in the European data as shown in a histogram of meteorite falls in Europe between 1750 and 1920 produced by Hawkins (1960) (see Fig. 3). A similar χ^2 test is used to compare the Chinese and European distributions with the null hypothesis that they are not different from each other. The analysis gives a value for $\chi^2 = 25.77$ and a probability of 0.08. The χ^2 value and its associated probability are not large enough to rule out the null hypothesis that the two distributions are not different.

Further χ^2 tests were performed on the Chinese data for the periods (1) 1600–1850, the dip in the 18th century; (2) 1500–1750, the peak centered at around 1600; and (3) 1550–1920, the whole interval encompassing all above features. We performed the χ^2 test again with the null hypothesis that the data are uniformly distributed. The analyses give, respectively, the following results (1) $\chi^2 = 56.42$ and a probability of 3.19×10^{-4}; (2) $\chi^2 = 44.63$ and a probability of 9.2×10^{-3}; and (3) $\chi^2 = 88.11$ and a probability of 4.7×10^{-6}. The small probabilities for all three cases suggest that the distribution is not uniform.

The above analyses suggest that variations in the observed frequency of meteorite falls may be real. We have already ruled out that fluctuations in population were the sole cause of these variations. We have also ruled out any political events that could have affected the long-term meteorite fall collection rate and the survival of the records. Other factors like changing perceptions, attitudes or interest toward meteorites that could affect the number of meteorite reports are difficult to assess. However, these factors can be counterbalanced by the interest generated by the appearance of a spectacular fireball in the sky and the curiosity in finding a stone that has fallen from the sky on the ground.

If the variations in the frequency of meteorite falls are not affected by population, wars or social attitudes, then could there have been a change in the meteorite fall influx rate? Recent studies claim evidence for the existence of groups of meteorite-producing asteroidal fragments (Halliday *et al.*, 1990; Drummond, 1991). It has been suggested that such groups of fragments may give rise to variations in the time history of meteorite falls. Treiman (1993) has also claimed evidence for a short-term variation in certain types of meteorite falls on time scales of a decade. From an examination of past records, he shows that falls of basaltic meteorites are not wholly random in time and that there was a significant cluster of falls from 1924 through 1939. However, gravitational perturbations will disperse Earth-crossing meteoroid streams on time scales that are much less than measured meteorite cosmic-ray exposure ages (Wetherill, 1985, 1988), strongly suggesting that streams and short-term variations in fall rates should not be observed.

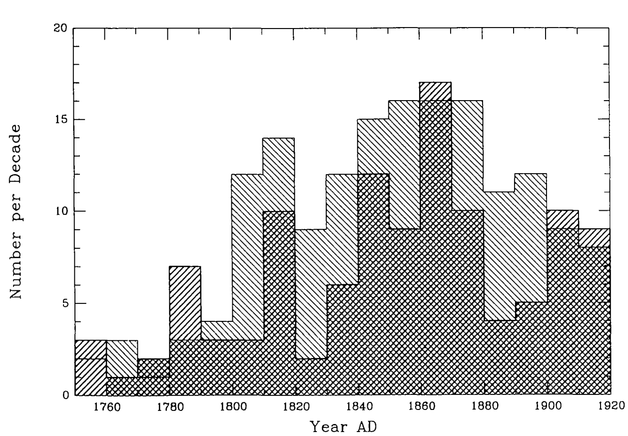

FIG. 3. Frequency distribution of meteorite falls in Europe (taken from Hawkins, 1960) is shown in a histogram with hatched lines to the right. The frequency distribution for China during the same period (same data as Fig. 2a) is also shown in a histogram with hatched lines to the left. The two data sets show similar trends.

Fall Rate

The total number of observed and recovered meteorite falls from China during the period from 700 B.C. to A.D. 1920 is 337. For reasons stated above, we will consider only the period after A.D. 1300. The number of observed and recovered meteorite falls in China between A.D. 1300 and 1920 is 274. The average number of falls per year for the whole of China is 0.44. The area of China is 9.6×10^6km^2 (*The Times Atlas of the World*, 1985). However, the local histories containing the observations cover only the native provinces of China. Six of the outlying provinces (Heilongjiang, Inner Mongolia, Jilin, Qinghai, Tibet and Xinjiang) do not have any meteorite fall records. Subtracting these areas, the considered area of China becomes 4.56×10^6km^2, yielding an average recovered fall rate of 0.1/year/10^6km^2. Since the land area of the Earth is 149 x 10^6km^2, this implies about 15 recovered falls per year for the entire world.

As already mentioned above, Brown (1960, 1961) deduced a range of rates observed at different localities of 0.32 to 1.1 falls/year/10^6km^2 from recovered witnessed meteorite falls, over a period of a century (1840–1939). The rate obtained from the Chinese data from 1840–1920 is 76 falls in 80 years or 0.21 falls/year/10^6km^2, which is a lower limit and in agreement with Brown. The inconsistency between the two results may have a number of explanations including lower population density in China and incomplete recording or reporting. The fall rates obtained by Brown and ourselves do not take into account seasonal and diurnal effects, which were included in the calculations by Hughes (1980).

REPORTS OF HUMAN CASUALTIES

Fatal injuries attributed to meteorite falls are extremely rare. For example, a Franciscan friar is reported to have died as a result of being struck on the thigh by a meteorite in Milan sometime between 1633 and 1664 (Cavagna and Vicentini, 1985). Another rather dubious report is of a farmer in Kentucky who may have been killed by a meteorite while sleeping in his bedroom on the night of 1879 January 14 (Hendricks, 1990). Also, an eight-pound meteorite fell on the ship Malacca going from Holland to Batavia in 1648 and is alleged to have killed two sailors (Wickman, 1993). Additional unconfirmed incidents of meteorites causing injuries to people may also be found in LaPaz (1958).

So far, the only authenticated incident of a relatively large meteorite actually hitting a person occurred in Sylacauga, Alabama. On 1954 November 30, a 3.9-kg stony meteorite struck a woman on the left hip and arm. It first fell through the roof and ceiling of her house, and then bounced off a large radio in the living room where she was taking a nap on a couch, before hitting her (Swindel, 1954). Recently, Jenniskens *et al.* (1994) report that a boy was hit on the head by a 3.6-g meteorite, which bounced off the leaves of a banana tree, while in the meteorite shower of 1992 August 14 in Mbale, Uganda.

In this section, we examine seven reported incidents of human casualties resulting from meteorite falls found in Chinese histories

(Table 1). These reports are taken from the same sources referenced in the previous section. From the descriptions given by a few of the entries in our catalog, we know that some of the meteorites were kept privately or sent to temples and preserved there. The whereabouts of the majority of the meteorites are not known. Since we do not have any samples of these meteorites, we can only rely on descriptions given in the texts for identification. The common term used to describe a meteorite is *yun-shih* (literally meaning a fallen stone). However, the character *yun* is often used as a verb, which then carries the meaning "to fall." Hence, one finds descriptions such as *shih-yun,* which means "a stone fell," or more commonly *hsing-yun,* which means "a star fell." In addition to recognizing these terms for meteorite falls, the context of individual records will have to be examined to ascertain a meteorite fall.

The A.D. 616 Meteorite

This event was recorded in chapters 4 and 21 of the *Sui-shu* (*History of the Sui Dynasty, 581–618*). The fireball associated with this event must have been very large and spectacular. Since the resulting fragment destroyed a wall-attacking tower, the meteorite was probably large, possibly tens to hundreds of kilograms in mass. However, the deaths may have resulted from the collapse of the tower, rather than a direct hit of the meteorite. The source of this event is one of the official dynastic histories, which should be highly reliable. The description of a fireball also suggests a meteoric event. An alternative explanation is that the event was associated with a military action taken against the rebel army. Possibly, this is the earliest human meteorite casualty event in recorded history.

The Yunnan Meteorite Shower of 1341

This occurrence appears to have been a shower of iron meteorites that fell over several areas of the province of Yunnan. There are a number of records for this event, all of which are contained in the local histories, and were likely eyewitness accounts. The mention of iron strongly suggests a meteoric origin because iron is rarely found in the pure metallic form on the Earth's surface. The records seem to indicate a heavy fall of meteorites vividly described as "iron rain." Also, the descriptions that "houses and hill tops were all with bore-holes" are consistent with modern reports of an iron meteorite shower (Buchwald, 1975).

Descriptions given in the various local gazetteers enable us to identify several fall sites from a historical atlas of the area (Tan, 1982). The meteorite showers were seen respectively at Kun-ming, Chin-ning, O-chia, Pin-ch'uan and east of Lake Erh-hai as shown in Fig. 4. An estimate based on the distances between the fall sites suggests that the showers must have fallen over an area at least 250 km x 100 km. However, that may be the region over which the shower was observed, and the actual fall zone may be considerably smaller. In order to cause the kind of devastation described by the reports, the parent meteoroid must have been fairly substantial. The reports bear some resemblance to the 1947 Sikhote-Aline iron meteorite shower in which meteorite fragments caused multiple small craters over a much smaller area of about 2 km^2 (Krinov, 1966).

The major weakness in this group of records is the uncertainty in the date of fall. The given year varies from 1321 to 1361. However, the various reports are fairly similar, suggesting that they are most probably describing the same event. Also, the closeness of the locations of the showers and the interval of time involved tend to rule out the possibility that these were individual records giving details of different incidents. The problem with the dates is probably due to copying errors. Many of the local histories underwent several stages of recompilation over the last few centuries. Further, the similarity in the names of the reign period at the time could have contributed to the confusion. We have checked the compilation dates for the local histories containing the records,

TABLE 1. List of human casualties.

No.	Date	Record	Ref.†
1.	616 Jan. 14	A large shooting star like a bushel fell onto the rebel Lu Ming-yueh's camp. It destroyed his wall-attacking tower and crushed to death more than 10 people.	a
2.	1321–23	(i) It rained iron to the East of Lake Erh-hai. Houses and hill tops were damaged with holes. Most of the people and animals struck by them wre killed. It was known as "the iron rain."	bi
	1341	(ii) In the O-chia district, the sky rained iron. Houses and hill tops were damaged with holes. Most of the people and animals struck by them were killed.	bii
	1342	(iii) It rained iron in Chin-ning. They damaged crops. Most of the people and animals struck by them were killed.	biii
	1361	(iv) In the Kun-ming district, iron rain fell from the sky. They damaged crops. People's houses were half in ruins.	biv
3.	1490 Feb./Mar.	(i) Stones fell like rain in the Ch'ing-yang district of Shansi Province. The larger ones were 4 to 5 catties [~ 1.5 kg], and the smaller ones were 2 to 3 catties [~ 1 kg]. They struck dead several tens of thousands of people.	ci
		(ii) Stones fell like rain in the Ch'ing-yang district. The larger ones were 4 to 5 catties [~ 1.5 kg], and the smaller ones were 2 to 3 catties [~1 kg]. They struck dead more than 10,000 people. All of the people in the city fled to other places.	cii
		(iii) Numerous stones rained in Ch'ing-yang. Their sizes were all different. The larger ones were like goose's eggs and the smaller ones were like water-chestnuts.	ciii
4.	1639	A large stone fell suddenly onto a small market street. It destroyed several tens of houses. The number of people killed amounted to several tens.	d
5.	1874 June 30	At night, during a thunderstorm, a huge stone fell from the sky at Chin-kuei Shan in Ming-tung Li. It crushed half of a cottage and killed a child.	e
6.	1907 Sept. 5	At Hsin-p'ai Wei in Weng-li, a stone fell. The whole of Wan Teng-kuei's family was crushed to death.	f
7.	1915 April 25	At 11 a.m., a meteorite fell in the Ta-yang village, east of the town Mai-po. It fell on a woman's shoulder and tore off her arm. The color of the stone was bluish black. There were four to five of them. The larger ones weighed more 10 catties [~ 3.5 kg]. The smaller ones weighed five to six catties [~ 2 kg].	g

† a. *Sui-shu,* chap. 4 and 21; bi. *Pin-ch'uan Chou-chih,* chap. 11; bii. *Yun-nan T'ung-chih,* chap. 17; biii. *Yun-nan Fu-chih,* chap. 25; biv. *Yun-nan T'ung-chih,* chap. 17; ci. *Wan-li Yeh-huo-Pien,* chap. 29; cii. *Ch'i-wen Lei-chi Chai-ch'ao,* p. 4; ciii. *Ming-shih,* chap. 28; d. *Ch'ang-shou Hsien-chih,* chap. 6; e. *Ho-chou Chih,* chap. 2; f. *Weng-an Hsien-chih,* chap. 8; g. *Fang-ch'eng Hsien-chih,* chap. 8.

and found all early versions prior to the Ch'ing Dynasty (1644–1911) give 1341 as the year of the fall.

The Ch'ing-yang Meteorite Shower of 1490

This incident can be found in a number of sources, including the official history of the Ming Dynasty (1368–1644), entry number 4(iii). The official records, which are usually reliable, serve as a confirmation that this incident did occur. However, the official history omits the number of fatalities. The description of "stones fell like rain" bears some resemblance to the largest stony meteorite shower seen in recent times near Jilin City, Jilin Province, China, on 1976 March 8 (Wasson, 1985). The Jilin meteorite shower, with a dispersion ellipse of 72 km x 8.5 km, landed more than 100 fragments with a total mass > 2700 kg. The largest of these fragments weighs 1770 kg, which is the largest stony meteorite known today.

The Ch'ing-yang incident seems rather implausible in terms of the total number of casualties and the narrow size distribution of the meteorite fragments. On the other hand, the Tunguska event of 1908 in which a meteorite exploded at ~ 8 km altitude with an estimated energy of 12 megatons, devastated an (unpopulated) area in Siberia ~ 40 km in diameter (Krinov, 1966), though there are no reports of meteorites reaching the ground. Tunguska-type events are predicted to occur with a frequency of 1 every 200 to 300 years (Shoemaker, 1983; Morrison, 1992). Such an event involving a somewhat larger stony meteorite exploding over a populated area might explain reports like this entry.

An alternative explanation is of meteorological origin. It is possible that the description "the larger ones were like goose's eggs and the smaller ones were like water-chestnuts" describes a hailstone shower. However, two stony meteorite showers, the

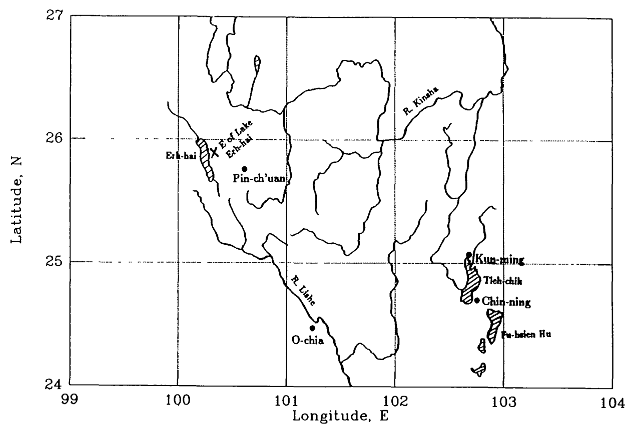

FIG 4. The fall sites of the Yunnan meteorite showers of 1341 and the general features of the region.

TABLE 2. List of structural damage.

No.	Date	Record	Ref.†
1.	588 June 25	During the casting of iron at the East Foundry, a red-colored object as large as several peck measures fell from the sky into the melting-pot. It was accompanied by rumbling noises like thunder. The [melted] iron flew over the wall and burned people's houses.	a
2.	1064	In the morning, at Chang-chou, there was a loud noise like thunder from the sky. A large star almost like the Moon was seen at the south-east. A moment later, there was another sound of thunder, this time from the south-west. Following another sound of thunder, the star fell into Mrs. Hsu's garden in the I-hsing district. It was seen by everyone near and far. Its flames brightly lit the sky. All of Mrs Hsu's bamboo fences were burned. After the fire had gone, a fairly deep hole as large as a cup was seen in the ground. Looking down it, one could see the glowing star was inside. After a while, the star was somewhat dimmer but still too hot to be approached. Later, the hole was dug out. At a depth of more than 3 *ch'ih* [~ 1 m], a round stone was obtained. It was still warm. It was as large as a fist with one end slightly tapered. It had a color like iron and also a weight like iron. The district governor Cheng Shen obtained it and sent it to Chin-shan Temple in Jun-chou. Even now, it is kept in a safe. It is on show when there are visitors.	b
3.	1504 Oct./Nov.	At the hour of shen [3–5 p.m.], in the western direction, a large star had fallen to the ground. It sounded like thunder and burned a cane garden.	c
4.	1639 Mar./Apr.	At night, a number of stars had fallen onto the houses in Fu-shi. They smashed roof tiles.	d
5.	1661 Aug./Sept.	At night, there was a sound like thunder. A stone fell into Mrs Yang's house. It was like a peck measure. It fell through the thatched roof and landed in front of the bed. It entered five *ts'un* [~ 18 cm] into the ground. Nobody was injured.	e
6.	1670 Nov. 7	At the hour of *szu* [9–11 a.m.], a star fell. It was as large as a peck measure. It fell from the sky with a sound. It broke the cross-beam of a house and entered about a *ch'ih* [~ 36 cm] into the ground.	f
7.	1844 Dec. 1	A total of 11 stones of various sizes fell. They all landed behind Li Wei-kung's Temple on Lo-shih Shan in An-chi. One of the stones damaged a wall of the sleeping chamber and another damaged a side-room on the north side of the temple.	g
8.	1845 May/June	A large stone fell near the Temple of the God of War outside the East Gate [of the city]. It damaged more than a hundred tombs on Kuan-shan [a hill], but no one was injured.	h
9.	1850 Oct. 17	At the hour of *hai* [9–11 p.m.], to the south-east of Szu-mao, within the dark clouds, a thundering sound like the beat of a drum was heard. The sound stopped for a moment and started again. Suddenly, the dark clouds broke apart. There was a large red star with a diameter of more than a degree followed by more than 10 small red stars. They fell streaming towards the north-west and landed more than 5 *li* [~ 2.5 km] from T'ing-ch'eng, just at the house of the Ho family in Tang Village. Mrs Ho was spinning cotton at the time. The star fell through the roof and landed next to the spinning-wheel. It entered into the ground and turned into a stone. It had a shiny black color outside. When it was hammered and broken apart, it had the color of silver ore inside.	i
10.	1879 Nov./Dec.	It rained stones in Huang-hsiang. They were as large as a peck measure or small as a fist. Many houses were damaged. The stones were as black as ore. They had a sulfur smell.	j

† a. *Ch'en-shu,* chap. 6; b. *Meng-ch'i Pi-t'an,* chap. 20; c. *Lung-hsi Hsien-chih,* chap. 5; d. *Yen-an Fu-chih,* chap. 1; e. *Ning-hsiang Hsien-chih,* chap. 2; f. *Wu-ch'ing Hsien-chih,* chap. 1; g. *Huchow Fu-chih,* chap. 20; h. *Ch'ang-shou Hsien-chih,* chap. 5; i. *P'u-erh Fu-chih,* chap. 2; j. *Ch'ang-ning Hsien-chih,* chap. 1.

Pultusk and Holbrook, contained in the *Catalogue of Meteorites* (Graham *et al.*, 1985) did produce more than 10,000 fragments. The Pultusk meteorite shower fell on 1868 January 30 over an area of several square miles between Pultusk and Ostrolenka on the Narew near Warsaw, Poland. The total number of fragments was estimated to be about 180,000 (Lang and Kowalski, 1971). The Holbrook meteorite shower fell on 1912 July 19 in Navajo County, Arizona, and landed about 14,000 fragments. If the Pultusk meteorite shower fell over a densely populated area, it might explain the number of fatalities and the narrow size distribution of the Ch'ing-yang incident.

The Ch'ang-shou County Meteorite of 1639

This was probably a substantial stone meteorite. The record indicates that several tens of houses were damaged and several tens of people were killed. It is unfortunate that the record does not give details as to the extent of the damage to the houses or whether or not a large meteorite fragment was left on the ground. The number of people killed was probably a result of the subsequent collapse of houses rather than the direct fall of the meteorite.

The Chin-kuei-shan Meteorite of 1874

According to the information given by the report, this was a fall of a large meteorite. The "thunder" may represent the sonic boom from the bolide. The coincidence between a meteorite fall and a storm is unusual. However, the description of the incident seems plausible.

The Hsin-p'ai-wei Meteorite of 1907

This was probably a fairly large meteorite as it was large enough to crush a house. The Wan family probably died from the collapse of the house, rather than from a direct hit by the meteorite.

The Ta-yang-chang Meteorite of 1915

This is a good witnessed meteorite fall record. As a relatively recent report, it is likely to have been compiled from a newspaper report published at the time of the fall . This is the only entry that reportedly resulted in bodily injuries rather than death. The weights given to the meteorites are consistent with meteorites commonly found today.

REPORTS OF STRUCTURAL DAMAGE

Given the larger area occupied by a building as compared to the area of a human being, the chance of a structure being struck by a meteorite is consequently higher. Although such reports are relatively uncommon, instances of these events can nevertheless be found in the published literature (Fessenkov, 1955; LaPaz, 1958; Graham *et al.*, 1985). We give, in Table 2, a list of meteorite falls that caused structural damage to buildings in China. Most of these are fairly straightforward descriptions, and virtually all appear to be highly plausible. The mention of thunder (sonic booms) and detonations is consistent with reports of meteorite falls from other parts of the world (Graham *et al.*, 1985). Two of the reports suggest that the meteorite was still burning when it landed. Reports of burning meteorites or meteorites hot enough to start fires were also found in other parts of the world (Merrill, 1930; Nininger, 1952). The existence of this class of meteorites has long been debated. Perhaps due to their frail and combustible nature, most of them do not deposit a surviving fragment on the ground. The rarity of finding a combustible meteorite on the ground could be one of the reasons why this class of meteorites is not easily recognized. However, modern research suggests that most meteorites are already cooled by the time they reach the ground (Bronshten, 1983). For the moment, this issue is unresolved.

INFERRED HIT PROBABILITY

The primary parameters in calculating the probability of a person on Earth being hit by a meteorite are the area occupied by a person and the rate with which meteorites reach the Earth's surface. Assuming that meteorites bombard the Earth's surface at random, the probability of a single meteorite striking a person is simply given by $\mu = na/S$, where n is the number of people on the Earth, a is the average projected area physically occupied by one person and S is the total surface area of the Earth. Then the probability, P, that at least one of the N individual meteorites falling per year will hit a person is

$$P = 1-(1-\mu)^N \simeq \mu N \qquad \text{Equ. (1)}$$

Based upon photographic observations of bright fireballs with a network of 60 cameras in Western Canada, Halliday *et al.* (1989) derived the following relation

$$\log N_f = -0.82 \log m + 3.40 \qquad \text{Equ. (2)}$$

where N_f is the cumulative number of falls/year/10^6km^2 with a mass of m grams or greater. According to Equ. (2), the rate of fall on the land area of the Earth for meteorites weighing over 0.5 kg is about 15.4 events/year/10^6km^2. Then, for the total land area of the Earth, the rate of incoming meteorites greater than 0.5 kg is about 2300/ year. Let the projected surface area of a person be 0.25 m^2 and the world population be 5×10^9 people, then $\mu = 8.4 \times 10^{-6}$. If we assume a half-kg meteorite as the lower limit for a meteorite that will kill a person, the probability of at least one impact resulting in a human fatality per year is 0.019, or one such impact every 52 years. Note, this may be considered an upper limit on the frequency of fatalities, since most people spend a large fraction of each day indoors, shielded by structures.

Halliday *et al.* (1985) predicted that one person would be struck (not necessarily resulting in serious injury) by a meteorite worldwide once every nine years, considering meteorites as small as 100 g and the projected surface area of a person to be 0.2 m^2. Calculations based upon our assumptions and the number predicted by Equ. (2) give the probability of a 100-g meteorite hitting a person per year for the world as 0.07 or once every 14 years.

The Chinese observations (Table 1) show that most fatalities were caused by large meteorites, and we consider the number of fatalities expected from such a class of meteorite. To simplify our argument, we take a 10-kg meteorite as the lower limit for the type of meteorites that caused fatalities in the Chinese records. The number of 10-kg meteorites expected to land on Earth is about 194 per year based on Equ. (2). The probability of such a meteorite hitting a person per year is 1.63×10^{-3} or one such event every 614 years. However, such an event might cause multiple fatalities as seen in the Chinese records.

The Chinese meteorite fall records contain five occurrences that resulted in direct human fatalities for the 620 years between A.D. 1300 and 1920. We discount the events of A.D. 616 and 1915 because the A.D. 616 event is outside the considered period, and the A.D. 1915 event did not actually cause a fatality. Based on simple statistics, this means one such event took place approximately every 124 years. During this period, the population of China rose from about 60 million in 1300 to around 430 million by 1900 (Durand, 1960), with an average population of about 140 million. The average value of μ is 7.7 x 10^{-6} (fairly close to the value of μ based on the current population for the entire Earth). Normalizing to the present day population on Earth and the total land area, we find that the number of reported fatal incidents in China from 1300 to 1920 implies a frequency of one fatal incident somewhere on Earth every 3.5 years. This is a surprising result, given the estimate above and the lack of recent public reports of such incidents.

DISCUSSION

In this paper, we have used Chinese histories to study two problems in meteoritics: the observed fall rate of meteorites on the Earth, and the historical occurrence of human casualties due to meteorite impacts. The observed fall rate of recovered meteorites shows long-term variations with time that cannot be totally explained by variations in population or by historical events which would have affected the reporting rate. One of these variations mirrors increases in the rate of observed and recovered meteorites in European records in the 19th century. The increase in rates in the 19th century most likely reflects an increased recognition of meteorites as extraterrestrial objects in European scientific circles, the increased European influence on Chinese scientific thinking, and the increased prestige then associated with collecting meteorites. Earlier variations may be associated with individual historians who found the meteorite more or less significant, resulting in apparent variations, especially when considering the small number statistics involved.

True variations in the fall rate of meteorites are not expected, given that the cosmic ray exposure ages measured for most meteorites are in excess of the times for meteoroid streams to dynamically disperse. Research papers suggesting evidence of meteoroid streams often count multiple meteorite types in their statistics; it would seem very unlikely that asteroids producing different meteoroid streams could coordinate their fall rates. We, thus, conclude that the variations in the fall rates we determine from the Chinese records are the result of unrecognized observational or reporting biases.

The unusually high estimate for the frequency of fatal incidents obtained with the Chinese records is difficult to reconcile with the estimate based on the Canadian data or with common experience. Although a number of explanations can be suggested, none appears satisfactory. For example, it is possible that the meteorite flux was higher during the period from 1300 to 1920 than during the more recent period when the Canadian data were taken. The short-term variations in the number of recovered meteorite falls shown in Fig. 2a are occasionally an order of magnitude or more. However, there is no conclusive evidence that fall rates were substantially higher in the past, and such variations in the rates are not expected (Wetherill, 1985, 1988).

The unusually high casualty rate in the Chinese records could be the result of small number statistics. Given five reports, the possible 1-σ statistical error is somewhat less than 50%, not enough to explain the discrepancy. Based on the results of current fireball observations (Halliday *et al.*, 1989), we would expect only a 28% probability of a single casualty report (from a 0.5-kg object or greater) in China over the 620 years of the local histories. An important point to reiterate is that the Chinese data appear to reflect only the more serious events related to large meteorites. The expected more common events of a single stone striking a single person, which should dominate the statistics in estimates like Halliday *et al.* (1985), do not seem to have been included.

It is possible that the Canadian network data underestimate the flux of meteorites reaching the Earth's surface. Huss (1990) derived a fall rate a factor of 3x higher than the Canadian network data from a combination of previous determinations. He used his derived rate to estimate ages for several Antarctic meteorite accumulations and showed that they generally agree with ^{14}C, ^{36}Cl, ^{26}Al, and ^{55}Mn dating of meteorites from a number of Antarctic ice fields. Another contributing factor could be that present reporting of meteorite fatality incidents worldwide is incomplete, particularly in regions of the world where meteorites are not readily recognized, or where communications are poor.

Given the past successes in the use of Chinese astronomical records, we are disappointed that the local histories appear to be less reliable in the case of the reported incidents of human fatalities. However, current experience with anecdotal records by nonprofessional observers is that they are often highly unreliable. It is possible that unexplained incidents were ascribed to meteorite falls when no other plausible explanation was available, or perhaps to cover up foul play. Sadly, there is no way we are aware of to confirm or refute further the reports listed in Table 1.

Finally, it is interesting to note that whatever the casualty rate related to meteorites was in the past, the rise in the population on Earth alone will render humans increasingly more vulnerable to these asteroidal fragments.

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