THE FALL OF THE ABEE METEORITE AND ITS PROBABLE ORBIT

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ABSTRACT

The Abee meteorite fell at 23^h05^m Mountain Standard Time on 9 June, 1952, about 80 km north of Edmonton. A 107-kg enstatite chondrite (E4) was recovered from a deep hole in a cultivated field a few days later (16 June) in latitude 54°12′55″ N, longitude 113°00′23″ W. We describe details of the luminous fireball, its path and the recovery of the meteorite. An error of 12^h in some published times of the event is noted. The apparent radiant derived from the visual data shows that the meteorite approached the Earth from approximately the antapex direction. If we accept the conclusion from recent studies of meteorite orbits that meteorites do not cross the orbit of Jupiter, then we may specify certain details of the Abee orbit. It is shown that the orbit had a very low inclination, that perihelion was near 0.95 AU, that the longitude of perihelion was near 225° and the velocity of entry into the atmosphere must have been within 2 km s^{-1} of 14 km s^{-1}.

Introduction. Of the 46 meteorites recovered in Canada, only eleven were witnessed falls. One of the most significant of these events was certainly the fall of the Abee, Alberta, meteorite in June 1952, since it provided a considerable mass of a relatively rare class of meteorite, one that has since been the object of very intensive study. (The name Abee is frequently mispronounced: the correct usage in the local area rhymes with "baby".) We present some previously unpublished details of the fireball that accompanied the event and we believe the orbit of the object can be derived with unusual confidence for a fireball that was recorded only visually.

Observations of the fireball. The fireball was widely observed in the area north of Edmonton, about 11:05 p.m. Mountain Standard Time, 9 June 1952 (6^h05^m U.T., 10 June 1952). The correct time of the event was listed by Millman (1953) in his catalogue of Canadian meteorites, but an error of exactly 12 hours appeared in some reports and catalogues (Dawson *et al.* 1960, Hey 1966, Douglas 1971) since the p.m. notation was missed.

At the latitude of the Abee fall (54°.2 N) there is continuous twilight during June nights. The sun was 10°.5 below the horizon at the time of the fall so the sky was moderately dark, but a twilight glow would persist low in the north-northwest. The long bright evenings contributed to the substantial number of observers who were outside and were witnesses to the fireball. One of the authors (A.A.G.) was in charge of the nearby Newbrook Meteor Observatory, only 13 km north of the impact point. Because of the bright nights, meteor photography is not practical near the summer solstice and the author was indoors. Although he did not witness the fireball, he heard the associated sonic booms, a sound similar to distant artillery fire that persisted for about a minute.

Visual observations of the fireball were collected by A.A.G. and by J.M. Grant of the Meanook Meteor Observatory in the days following the fireball. Further interviews were conducted by A.A.G. and P.M.M. during the weeks following the recovery of the meteorite. More than a dozen reports were collected from observers near Edmonton, Thorhild, Athabasca and Newbrook. These locations provided good coverage from both sides of the path, and after discarding a few inferior reports, the best location of the apparent radiant was found to be near azimuth 300° and elevation 18°, *i.e.* the meteorite entered the atmosphere on a relatively flat path from a direction between northwest and west.

All observers were impressed by the brightness of the fireball. Most described it as much brighter than the Full Moon while a few compared it to daylight. There were broken clouds in the area and some saw the fireball through light clouds. One said it lit up the face of a companion much more than in bright moonlight. At Spedden, roughly 80 km beyond the impact point, a witness in a drive-in theatre reported that the light from the fireball blanked out the picture. The fireball would have been only 10 or 15° above the horizon as seen from Spedden, so its light could strike a theatre screen very effectively.

The shape of the fireball was usually described as round, with a short tail. Estimates of the angular size varied from less than half a lunar diameter to somewhat larger than the Moon, without much correlation with the observer's distance from the path. Observers near the end of the trail tended to report two lesser fragments trailing the main object after a flare, late in the flight. The recovered meteorite exhibits one surface where it appears that a minor portion had broken away, called the "scar area" by Dawson *et al.* (1960) and shown in their figure 2. Only one large piece was ever recovered and it is believed with confidence that it represents the major surviving mass. Smaller pieces might have fallen several kilometres short of the main one and although no systematic search was undertaken, there was a local awareness that other fragments might be found. The observations indicate a height near 15 km for the point of fragmentation, near latitude 54°20′ N and longitude 113°19′ W, but only limited confidence can be placed in the height estimate since visual estimates of angular elevations tend to be discordant.

The most common colour mentioned for the fireball was red, although orange, yellow, blue and white were also mentioned by some witnesses. There is typically less agreement about the colour than other aspects of the description of spectacular meteors.

Some observers stated that only the final few seconds of the event were seen, whereas others estimated durations ranging from 15 s to a minute. It will be shown later in this paper that the entry velocity must have been close to 14 km s^{-1}, near the slow end of the range of meteorite velocities. Since the radiant was low in the sky, a long duration is expected. We may compare the Abee event with the Fork Lake, Alberta, fireball of 1980 September 1, photographed by the MORP (Meteorite Observation and Recovery Project) camera network (MORP no. 580) described by Halliday *et al.* (1989a). The Fork Lake event was photographed for 18 s and was among the three or four most massive events recorded by the network, although the terminal mass is estimated at a tenth of the Abee mass. Fork Lake also entered the atmosphere at 14 km s^{-1}, on an even less steep path than Abee. The Abee event was observed to a much lower height than Fork Lake, however, so it is reasonable to expect the Abee fireball would have been visible for at least 15 to 20 s. This is supported by several observers who described Abee as slow or of medium speed.

Individual estimates of heights based on visual data may be unreliable, as mentioned above, yet there are two aspects of the Abee reports that appear to be consistent and of some interest. Those who reported seeing early portions of the path indicated angular elevations that did not correspond to heights greater than 41 km, given the locations of the observers. There is no doubt that the fireball must have been quite bright at any height below about 75 km, but the fact that the meteorite approached from the direction of the persistent twilight, combined with the broken clouds, indicates that it was not noticed until it became extremely bright at lower heights.

Of even greater interest are the reports of three observers who were less than 15 km from the impact point, two on the north side and one on the south side of the path. If the light had ended at a low value of only 10 km above ground, it should still have been well up in the sky for these observers. All three indicated that they followed the object down to a height near 1 km above ground (1.6 km above sea level) as did a fourth observer who was somewhat more distant. Three of these four reported the colour as red. At this height, the meteorite must have decelerated well below the point where ablation had stopped, but perhaps the long atmospheric path had heated the outer layer sufficiently for a reddish glow to be observable by those who were close to the end point.

Witnesses closer than about 30 km from the late portions of the ground path reported sounds, usually described as a rumble about a minute after the light was seen. A few recalled an explosion followed by a rumble. There were no convincing reports of the anomalous sounds that sometimes accompany the luminous phenomenon (Keay 1980, 1990) although one person located 40 km from the path mentioned a sound like rushing wind soon after the light was seen. We hesitate to attach much importance to this single report.

FIG. 1—Mr and Mrs Harry Buryn (and unidentified friend) with the Abee meteorite just after its recovery, June 16, 1952.

Recovery of the meteorite. There was much local discussion of the fireball in the days following the event and a general awareness that a meteorite had almost certainly landed in the area north of Edmonton. When Harry Buryn spotted a deep hole in his freshly seeded wheat field on Saturday, June 14, he mentioned the unusually large hole to his neighbour, a school teacher. She thought of the fireball and informed the first author (A.A.G.) late on June 15. When he arrived on the scene with a camera the following morning, a group of students had already excavated the meteorite (see figure 1). Small students had climbed into the hole and secured ropes around the stone to haul it to the surface. As previously reported by Dawson *et al.* (1960) the hole was about 0.7 m in diameter and 1.5 m in depth, an indication of the penetrating ability of a sizeable meteorite in cultivated soil. The hole had a slope of about 25° to the vertical, with the bottom displaced to the southeast, indicating the direction of arrival was approximately from northwest.

The location of the fall is given by latitude 54°12′55″ N, longitude 113°00′23″ W. In the system of land descriptions on the Canadian prairies, the field is identified as SE $^1/_4$, Section 25, Township 60, Range 21, west of the Fourth Meridian. (Each township consists of 36 sections of one square mile, while a section is normally divided into quarters; thus the description defines the location within a square area 805 metres on a side). The meteorite was first taken to the hardware store in Newbrook where its weight was established as 107 kg and it was prominently displayed for a few weeks. Later it was moved to the grain elevator in the hamlet of Abee until arrangements were completed for its purchase by the Geological Survey of Canada for the Canadian National Meteorite Collection in Ottawa. The Abee meteorite proved to be a brecciated enstatite chondrite of class E4. Samples have been distributed widely and it has been studied in great detail.

Orbit of the Abee meteorite. To determine the orbit followed by a meteorite before its collision with the Earth, we require the date, time and location of the event, the radiant direction from which the object approached the Earth, and the velocity on entry into the atmosphere. A set of acceptable visual observations can provide good values for all these quantities with the exception of the velocity. An error of 20 per cent in estimating the velocity may cause a major change in the orbit derived, and the confidence that can be placed in a visual observer's estimate of the duration of a fireball is rarely as good as 20 per cent. This is the reason that networks of camera stations were required to obtain acceptable orbits for meteoritic fireballs.

Before many data were available from the camera networks, Millman (1969) completed a study of meteorite orbits using the best velocity estimates in the literature for some 25 meteorites. With the exception of the Příbram meteorite that had been photographed in 1959 (Ceplecha 1961) the velocities relied on visual observers. Abee was included in this study and the entry velocity was taken to be 18.0 ± 3.0 km s^{-1}, based on timing the actions of some observers during the interviews in 1952. The paper did not present individual orbits for the 25 meteorites, because of the uncertainties described above, but dealt with the probable range of orbital elements for the entire group.

Today we have a wealth of data from the fireball camera networks and a relatively secure knowledge of which fireballs and orbits are associated with meteorite falls (McCrosky *et al.* 1976, Halliday *et al.* 1989a, 1989b). Typical meteorite orbits have low inclinations to the ecliptic with perihelia between Venus and Earth and aphelia inside the orbit of Jupiter. All meteorites appear to travel in direct orbits, with their orbital motion in the same direction as the planets. Among the reliable orbits there is not a single violation of the rule that meteorite orbits do not cross the orbit of Jupiter. If we apply this limitation to meteorites with only visual observations, we can occasionally place surprisingly tight restrictions on the entry velocity and derive an orbit that must be close to the true orbit.

When we consider the intersection of a meteorite's orbit with the orbit of the Earth, we may view it in two ways. From the point of view of an observer looking down on the solar system, the elliptical orbit of the meteorite intersects that of the Earth at some angle that is less than a right angle, relative to the antapex of the Earth's motion (the direction opposite to the Earth's orbital motion). This follows from our observation that all meteorites travel in direct orbits. If the meteorite has a perihelion well inside the Earth's orbit, the intersection occurs at a much greater angle with respect to the antapex direction than if perihelion is only slightly inside our orbit. We normally view the event from the moving Earth, however, not from a detached location. In this system, the apparent direction of approach is much altered by the Earth's orbital motion and the entry velocity into the atmosphere becomes the relative orbital velocity of the bodies. (Both the direction and the velocity are modified to a known extent by the Earth's gravitational attraction.) The change in the apparent direction is greatest when the relative velocity is low and this occurs for meteorites (with low-inclination orbits) if perihelion is only slightly inside our orbit. In such cases the meteorite is essentially overtaking the Earth from behind. The effect is the same whether the meteorite is approaching perihelion or has started back out, although the former case will have a greater proportion of night-time events.

These facts can be used to our advantage to derive orbits from visual observations for those meteorites that have perihelion distances appreciably larger than 0.9 AU, provided the orbit has the normal small inclination to the ecliptic. These are the slowest possible meteorites, with entry velocities in the range from 11 to about 15 km s^{-1}. Small changes in the heliocentric radiant are magnified to much larger changes in the geocentric radiant, so a typical error of up to about 10° in determining a visual radiant leads to a much smaller error in the heliocentric direction. If we assume increasingly large entry velocities, the aphelion point quickly moves out to, or beyond, the orbit of Jupiter, violating our observed rule that meteorite candidates do not arrive in such orbits. Unless the meteorite in question has an orbit that is entirely different from the dozens of cases studied by the camera networks, we may be able to specify the velocity with a precision far greater than can be derived from estimates by the observers themselves. Some of the orbital elements may be equally well defined.

The potential of this approach has been shown by Halliday and McIntosh (1990) with reference to the important Murchison, Australia, fall in 1969. The radiant was well defined by visual observations and it was shown that perihelion was very close to the Earth's orbit with an entry velocity within 15 per cent of 13 km s^{-1}.

The apparent radiant of the Abee meteorite was near azimuth 300°, elevation 18°, not very remote from the antapex direction at the time of the event. We adopted a grid of 12 points surrounding this best value, with elevations of 13, 18, 23 and 28° for azimuths of 290, 300 and 310°. We believe the real direction of the apparent radiant should lie within these boundaries. For each of these possible radiants we calculated orbits for entry velocities of 12, 14, 15, 16 and 18 km s^{-1}, for a total of 60 orbits.

Of the 60 test orbits, about 40 per cent would be considered normal orbits for meteorites, one third would be classified as unacceptably large and the remaining one quarter as unusual, but possibly acceptable orbits. Table I shows a selection of five orbits, chosen to illustrate the three groups. Orbits A and B are considered to be quite acceptable, orbit C is a marginally acceptable solution with a low entry velocity, orbit D is marginally acceptable at the high-velocity end, and orbit E is unacceptable. Successive rows in Table I show: the entry velocity v_∞; the assumed azimuth and elevation of the apparent radiant, A and h; the right ascension and declination of the geocentric radiant, corrected for the Earth's gravitational effects, α_R, δ_R; the orbital elements, semi-major axis, a in AU; the eccentricity, e; the inclination, i; the perihelion distance, q in AU; the aphelion distance q'; the argument of perihelion, ω; the longitude of the ascending node, Ω; and the longitude of perihelion, $\tilde{\omega}$, defined as $\omega+\Omega$. The final two rows show the angular distance of the corrected radiant from the antapex direction in both the geocentric and heliocentric systems, defined as $180° - \lambda_G$ and $180° - \lambda_H$, where λ is the more commonly quoted elongation of the radiant from the apex direction. The orbital elements are listed in the same order (although we now use Ω and $\tilde{\omega}$ rather than θ and Π) as in Halliday *et al.* (1989a) to which the reader is referred for a normal selection of meteorite orbits.

Let us consider the data in Table I. For slow meteorites the zenith attraction correction is large if the radiant is low in the sky, *i.e.* the apparent radiant is much closer to the zenith because of gravitational bending of the path than is the true radiant. The true radiant may be located below the horizon; in other words the meteorite would have missed the Earth entirely if its path had not been deflected by gravity. The corrected radiant for solution C is well below the horizon and the radiant for solution A is slightly below the horizon, while for solution B the radiant is just above. The acceptable range of orbits is limited by what we consider the acceptable range of the aphelion distances, q'. This restricts the values of a and e to moderate values but leaves them not well defined. The inclination of the orbit to the ecliptic is very small for all the radiants used in these calculations. The perihelion distance appears to be close to 0.95 AU

TABLE I
ORBIT SOLUTIONS FOR THE ABEE METEORITE

	Acceptable		Marginally Acceptable		Unacceptable
	A	B	C	D	E
v_∞	14.0	15.0	12.0	16.0	18.0
A	300.0	300.0	290.0	310.0	300.0
h	18.0	18.0	13.0	28.0	18.0
α_R	119.6	121.6	115.9	121.3	125.0
δ_R	15.1	18.2	−8.8	35.8	23.4
a	1.85	2.32	1.28	2.53	8.45
e	0.483	0.591	0.233	0.631	0.889
i	1.4	0.6	4.5	4.8	1.4
q	0.954	0.950	0.982	0.934	0.939
q'	2.74	3.69	1.58	4.13	15.97
ω	324.7	325.8	325.7	142.3	147.1
Ω	259.2	259.2	259.3	79.3	79.3
$\tilde{\omega}$	223.9	225.0	225.0	221.6	226.4
$180 - \lambda_G$	50.5	49.1	54.3	54.5	47.1
$180 - \lambda_H$	11.0	12.2	7.4	14.8	15.1

All angles are in degrees. v_∞ is in km s^{-1}, h is in km, and a, q and q' in AU.

and is unlikely to lie outside the range from 0.93 to 0.98, so it is rather well determined, but not with as much precision as the value of 0.99 to 1.00 found for the Murchison meteorite.

Solutions C and D correspond roughly to orbits with aphelion distances such that we expect about 10 per cent of meteorite orbits to have smaller values of q' than orbit C and about 10 per cent to have larger values than orbit D. This is based on the 44 orbits in Halliday *et al.* (1989a) but it should be expected that if the data in that paper could be corrected for error dispersion, then the distribution of q' would be more strongly peaked near values of 3.0 and an even smaller proportion would lie outside the limits implied by orbits C and D. The values of ω and Ω are well defined except that both values decrease by 180° in solutions D and E. In the other solutions the zenith attraction correction moves the true radiant south of the ecliptic, so that the collision with Earth occurs at the ascending node. This is almost certainly the real situation, whereas with the improbably high entry velocities in D and E, the nodes are interchanged. The longitude of perihelion, $\tilde{\omega}$, is not affected by this possibility and it is seen to be very well defined, near 225°. This is a key quantity when one searches for orbits that may indicate a common source for a group of meteorites. Four such groups were found in the camera network data by Halliday *et al.* (1990) but the orbit of the Abee meteorite does not resemble any of these groups.

The final two rows of Table I show how the small angle between the heliocentric radiant and the antapex direction (bottom row) increases when viewed from the moving Earth (next to last row). Although the corrected radiants for orbits A and C differ in position by 24°, the angular displacements from the antapex are comparable since most of the change is in the transverse direction.

All 12 orbits computed with an entry velocity of 14 km s^{-1} are acceptable, with a range from 2.19 to 3.51 AU for the aphelion distance. All orbits with a low v_∞ of 12 km s^{-1} are also possible, but their aphelia are smaller than normal, from 1.38 to 1.77 AU. At 15 km s^{-1}, one quarter of the aphelion values are approaching the orbit of Jupiter, while at 16 km s^{-1}, only those with azimuth values A of 310° are acceptable. At 18 km s^{-1}, all aphelia lie beyond Jupiter and two orbits have actually become hyperbolic. We conclude that the most probable entry velocity is closer to 14 than 15 km s^{-1} and the range of acceptable values lies within 14.0 ± 15%. This overlaps the range suggested by Millman (1969) of 18.0 ± 3.0 km s^{-1}, but Abee must have been among the group of slow meteorites.

Conclusions. The radiant position of the Abee fireball combined with current knowledge of meteorite orbits indicates that it arrived in a low-inclination orbit with perihelion near 0.95 AU. The meteorite was not subjected to temperatures or a cosmic-ray environment that might be found inside the orbit of Venus. Abee had passed perihelion about a month before collision with the Earth, which is unusual for events relatively close to midnight, but is not improbable at higher latitudes near the summer solstice. Most probably it was at the ascending node of its orbit. The entry velocity into the atmosphere must have been within the range 14 ± 2 km s^{-1} and the visual observations indicate there was a fragmentation event late in the flight, probably near a height of 15 km.

This paper is based on data collected by A.A.G. and P.M.M. in 1952, augmented by more recent data from meteorite camera networks. The paper was written after the death of Dr Millman in December, 1990, in order to fulfil a longstanding wish of Dr Millman's that the Abee meteorite fall should be documented to the fullest extent possible.

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