The Meteoritical Society

Meteoritics & Planetary Science 1–33 (2010)
doi: 10.1111/j.1945-5100.2010.01116.x

The recovery of asteroid 2008 TC_3

Muawia H. SHADDAD[1], Peter JENNISKENS[2*], Diyaa NUMAN[1], Ayman M. KUDODA[1], Saadia ELSIR[3], Ihab F. RIYAD[1], Awad Elkareem ALI[4], Mohammed ALAMEEN[1], Nada M. ALAMEEN[1], Omer EID[1], Ahmed T. OSMAN[1], Mohamed I. AbuBAKER[1], Mohamed YOUSIF[1], Steven R. CHESLEY[5], Paul W. CHODAS[5], Jim ALBERS[2], Wayne N. EDWARDS[6,7], Peter G. BROWN[6], Jacob KUIPER[8], and Jon M. FRIEDRICH[9,10]

[1]Department of Physics, University of Khartoum, P.O. Box 321, Khartoum 11115, Sudan
[2]SETI Institute, Carl Sagan Center, 189 Bernardo Avenue, Mountain View, California 94043, USA
[3]Department of Physics, Juba University, P.O. Box 321, Khartoum 11115, Juba, Sudan
[4]Department of Chemistry, University of Khartoum, P.O. Box 321, Khartoum 11115, Sudan
[5]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109, USA
[6]Department of Physics and Astronomy, University of Western Ontario, London, Ontario N6A 3K7, Canada
[7]Canadian Hazards Information Service, Natural Resources Canada, 7 Observatory Crescent Ottawa, Ontario K1A 0Y3, Canada
[8]Royal Netherlands Meteorological Institute, Wilhelminalaan 10, 3732 GK De Bilt, The Netherlands
[9]Department of Chemistry, Fordham University, 441 East Fordham Road, Bronx, New York 10458, USA
[10]Department of Earth and Planetary Sciences, American Museum of Natural History, 79th Street at Central Park West, New York, New York 10025, USA
[*]Corresponding author. E-mail: petrus.m.jenniskens@nasa.gov

(Received 25 January 2010; revision accepted 17 September 2010)

Abstract–On October 7, 2008, asteroid 2008 TC_3 impacted Earth and fragmented at 37 km altitude above the Nubian Desert in northern Sudan. The area surrounding the asteroid's approach path was searched, resulting in the first recovery of meteorites from an asteroid observed in space. This was also the first recovery of remains from a fragile "cometary" PE = IIIa/b type fireball. In subsequent searches, over 600 mostly small 0.2–379 g meteorites (named "Almahata Sitta") with a total mass 10.7 kg were recovered from a 30×7 km area. Meteorites fell along the track at 1.3 kg km^{-1}, nearly independent of mass between 1 and 400 g, with a total fallen mass of 39 $\pm$ 6 kg. The strewn field was shifted nearly 1.8 km south from the calculated approach path. The influence of winds on the distribution of the meteorites, and on the motion of the dust train, is investigated. The majority of meteorites are ureilites with densities around 2.8 g cm^{-3}, some of an anomalous (porous, high in carbon) polymict ureilite variety with densities as low as 1.5 g cm^{-3}. In addition, an estimated 20–30% (in mass) of recovered meteorites were ordinary, enstatite, and carbonaceous chondrites. Their fresh look and matching distribution of fragments in the strewn field imply that they were part of 2008 TC_3. For that reason, they are all referred to as "Almahata Sitta." No ureilite meteorites were found that still held foreign clasts, suggesting that the asteroid's clasts were only loosely bound.

INTRODUCTION

Twenty hours before impact, a small (3–4 m sized) asteroid was discovered by Richard Kowalski of the Catalina Sky Survey at Mt. Lemmon Observatory on October 6, 2008 (McGaha et al. 2008). The asteroid was later designated "2008 TC_3." Unlike all others before it, this asteroid was found to be on an impact trajectory with Earth. At 11 h before impact, Chesley (in McGaha et al. 2008) reported that the asteroid impact would occur over northern Sudan, entering the atmosphere at 50 km altitude above an oblate Earth early the next day

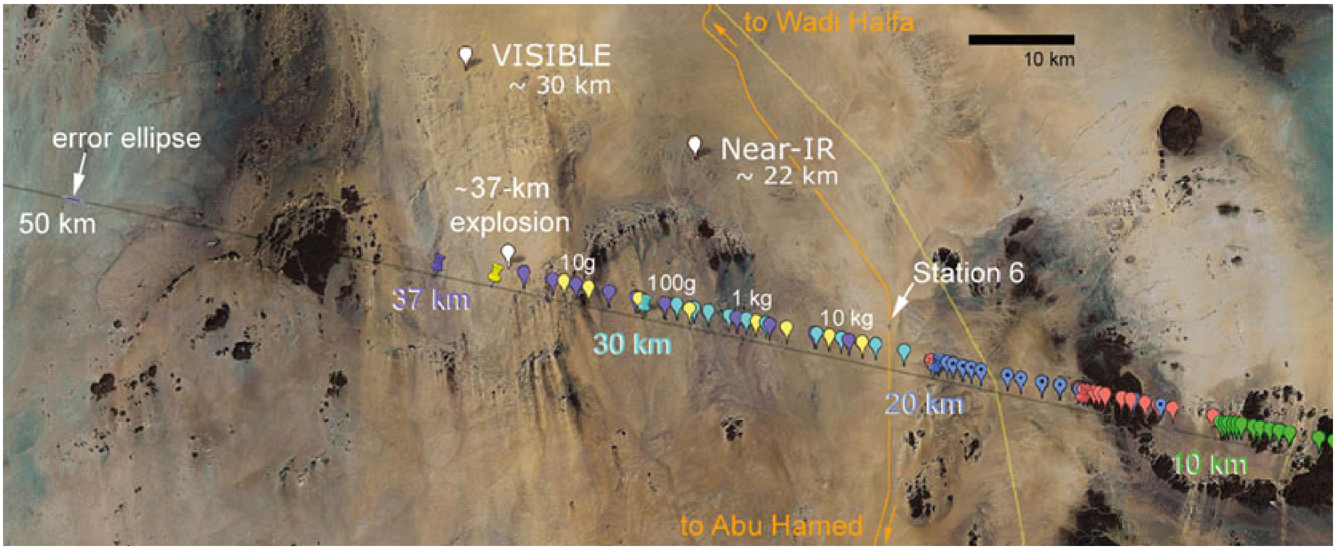

Fig. 1. The 60×10 km fall area of 2008 TC_3 is located just southwest of Station 6 in the Nubian Desert (using *Google Maps*). The ground-projected trajectory of the asteroid, moving from left to right, is that known in late November, 2008 (Table 1), with the error range shown at the 50 km point. Balloons show the predicted impact points, based on the UWO fall model and the UKMO wind model, for masses of 2, 5, 10, 25, 50, 100, 500 g, 1, 2.5, and 5 kg (from left to right) that were released with 4 km s^{-1} residual speed at altitudes of 37 km (purple), 35 km (yellow), 30 km (cyan), 20 km (blue), 15 km (red), and 10 km (green). The map also shows the early projections from Meteosat 8 (''visible'' and ''near-infrared'') and locations reported from U.S. government satellite observations (37 km explosion). The orange line shows the actual road between Abu Hamed and Wadi Halfa (the yellow line on the Google map being in error, this has since been corrected).

Table 1. Observed approach trajectory for asteroid 2008 TC_3.[a]

Altitude (km)	JD +2454746.0	UTC October 7, 2008	Longitude (°) WGS84	Latitude (°) WGS84	Speed (km s^{-1})	Zenith angle (°)
100	0.614936227	2:45:30.5	30.55173	21.09330	12.78	69.99
90	0.614962626	2:45:32.8	30.79745	21.04793	12.79	70.15
80	0.614989202	2:45:35.1	31.04547	21.00172	12.80	70.30
70	0.615015961	2:45:37.4	31.29583	20.95466	12.81	70.45
60	0.615042907	2:45:39.7	31.54859	20.90672	12.81	70.61
50	0.615070045	2:45:42.1	31.80381	20.85787	12.82	70.76
40	0.615097381	2:45:44.4	32.06155	20.80810	12.83	70.92
30	0.615124920	2:45:46.8	32.32186	20.75739	12.84	71.08
20	0.615152669	2:45:49.2	32.58481	20.70569	12.84	71.25
10	0.615180632	2:45:51.6	32.85048	20.65299	12.85	71.41
0	0.615208817	2:45:54.0	33.11893	20.59926	12.86	71.57

[a]Speed is the geocentric speed relative to Earth's center after including acceleration from Earth's gravitational field. No atmospheric deceleration included. Trajectory calculated by SRC based on the asteroid's orbit trajectory JPL Solution 15.

at 02:46 UTC on October 7. The asteroid arrived at 12.4 km s^{-1} (measured relative to the Earth surface and the atmosphere, 12.82 km s^{-1} relative to the Earth center) on a shallow 19.14° elevation angle from azimuth 281° as measured eastward from True North (Fig. 1), and from a geocentric radiant of RA = 348.1°, Decl. = +7.6°, V_g = 6.45 km s^{-1} at solar longitude 194.2° (J2000). The asteroid was expected to cause a brilliant fireball event and ''would be very unlikely to survive the atmosphere intact'' (McGaha et al. 2008).

One hour prior to atmospheric entry, Chodas (2008) gave an update, estimating the entry into Earth's atmosphere at around 2:45:28 UTC ± 15 s, with the asteroid expecting to reach maximum deceleration at an altitude of about 14 km around 2:45:54 UTC (the timing was later modified, see Table 1). The time at which any fragments might reach the ground depended on the unknown physical properties of the object, but was thought to be 52 s later, around 2:46:20 UTC ± 40 s. At the time, the footprint uncertainty was ''less than some tens of km.''

The impact was observed by the *Meteosat 8* satellite, from which Borovička and Charvát (2008) reported that the geographical coordinates of the spot in the visual and near-infrared channels were at longitude = 32.16°E and latitude = +20.97°N (WGS-84 ellipsoid), assuming that the source of light was at sea level (which it was not). The infrared channels (displaced in the instrument focal plane) scanned the region 1.8 s later and showed the spot at 32.37°E, +20.89°N. It was noted by Borovička and Charvát (2008) that "the actual coordinates may be slightly southwest of these positions after correcting for the fireball's altitude (about 30 and 22 km)." Independent confirmation came from U.S. government satellites which detected the impact of the bolide first at 02:45:40 UT (Brown 2008; Chesley et al. 2008). It was stated that the initial observation put the object at 65.4 km altitude at 31.4°E, 20.9°N, while the object detonated at an altitude of approximately 37 km at 32.2°E, +20.8°N.

These coordinates were not in exact agreement with each other, nor with the predictions. The predicted altitude of deceleration was incorrect because the asteroid fragmented much higher in the atmosphere than typical fireballs of ordinary chondrite composition (e.g., Jenniskens et al. 1994; Borovička and Kalenda 2003; Brown et al. 2005; Jenniskens 2006). Indeed, initial searches by University of Khartoum staff for meteorites near the positions reported by Borovička and Charvát (2008) in the days following the impact were unsuccessful. Because of the reported high explosion altitude, it was initially thought that no meteorites could be recovered.

From the satellite observations alone, however, it was not immediately clear to what depth the asteroid had penetrated. Did the detonation at 37 km represent the end point of the fireball, or did it continue down to 30 or 22 km, as guessed by Borovička and Charvát (2008), or even 14 km altitude, the point of peak deceleration according to Chodas (2008)? Was the asteroid trajectory still uncertain by several tens of km (also perpendicular to the track?) after all available astronomical observations had been gathered?

Because of the shallow approach trajectory, the potential search area was very large: about 60 km long and 10 km wide (Fig. 1). The fragmentation scatters meteorites both along (W–E) and across (N–S) the trajectory, possibly in a size-dependent manner. The search area was narrowed down further by including the latest astrometric data on the asteroid's approach path. The calculated trajectory (Table 1; solid line in Fig. 1) was derived without taking into account the interaction with the Earth's atmosphere, which would have decelerated the asteroid and caused ablation and fragmentation. The nominal position at 50 km altitude above the WGS-84 ellipsoid (before major fragmentation is presumed to have occurred) was uncertain by only ±120 m cross-track and ±700 m along track (Jenniskens et al. 2009). This greatly constrained the search area to a band along the projected approach path. Until then, meteorite recoveries had been assisted solely by multistation fireball observations, such as in the recent work by Bland et al. (2009).

Atmospheric drag and winds too act differently on meteorites of different size, shape, and density. A simple falling sphere model, assuming an ejection speed of 10 km s^{-1} at the 37 km point suggested that most meteorites would have fallen close to the approach trajectory. In addition, we ran the University of Western Ontario dark flight model, which included ablation after breakup. A modest 4 km s^{-1} residual speed at the time of release was adopted, which is typical of other falls (Borovička and Kalenda 2003; Klekociuk et al. 2005). For a range of breakup altitudes, most meteorites were calculated to have fallen a few hundred meters north of the trajectory, independent of mass (Fig. 1). We concluded that a better understanding of the breakup altitude was needed to shorten the search area in the along-track direction, which could perhaps be obtained from eyewitness accounts and triangulation of the cell phone images of the dust cloud.

At the invitation of the University of Khartoum, P. J. traveled to Sudan and gave a presentation at the Physics Department on December 3, 2008, after which M. H. S. and P. J., in the company of eyewitness Mohammed Elhassan, traveled to the fall area to speak with other eyewitnesses, where they were later joined by a team of students and staff of the University. At train station 6, eyewitness Abdel Moniem Magzoub, the station attendant, reported that the fireball terminated east from his location, consistent with the 37 km explosion point reported earlier. Dust train observations from Wadi Halfa, too, suggested that the fireball had exploded unusually high in the atmosphere, where the dust train terminated in a dense cloud.

Because no larger fragments were seen penetrating to lower altitudes, it was decided to search for possible smaller surviving fragments just downward from the explosion point. Forty-five students and staff of the University of Khartoum participated in the search (Fig. 2). After only 2 h, student Mohammed Alameen found the first meteorite in the late afternoon of December 6, 2008. These meteorites were later named "Almahata Sitta" (Weisberg et al. 2009), meaning "Station 6" in Arabic. The first investigated sample, #7, was determined to be an anomalous polymict ureilite (Jenniskens et al. 2009). This was the first observed fall of a polymict ureilite (e.g., Goodrich 1992; Cloutis et al. 2010). These finds and the initial study of the #7 meteorite were previously reported by Jenniskens et al. (2009). A significant fraction of other fresh-looking meteorites found in the strewn field, however, have since been recognized to be of different types, including enstatite and ordinary chondrites. All appear to have originated from 2008 TC_3.

After the initial recovery, three more search campaigns were organized to better constrain the distribution of fragments in the strewn field. Here, we elaborate on the observations that guided these meteorite searches and report on the location of all recovered meteorites in the strewn field relative to the calculated approach trajectory, and as a function of meteorite density and type. This work serves as an introduction to other studies of the recovered meteorites and parent asteroid 2008 TC_3.

EYEWITNESSES OF FIREBALL AND TRAIN

The area of interest was located just south of Station 6 in the Nubian Desert of northern Sudan (Fig. 1). Station 6 is one of the 10 stations along a railroad between Wadi Halfa and Abu Hamad. It is the only station with potable water and was permanently inhabited by a small group of people at the time, including the station attendant and a family owning a truck stop comprising a tea house and shelter. At the time, the first tarmac road from Wadi Halfa south to Dongola (which now runs along the Nile River) had not yet been finished, but was completed in late 2009. Until that time, the sandy plain adjacent to the railroad served as the main road between Sudan and Egypt.

Interviews with eyewitnesses were conducted on 2008 December 3–5, in the region of the fall in Nile Province. At Station 8, we learned from a group of locals that the fireball was seen at Abu Hamad south of the trajectory. It was a bright meteor, without visible breakup at the end.

At Station 6 (20°45.207′N; 32°32.946′E), we spoke with station attendant Abdel Moniem Magzoub, who was sleeping on the porch of the station when he was woken up by a bright light. He immediately sat up, saw the meteor moving toward him, continuing for another second or so, before it abruptly ended. No pieces were seen to continue. After 2–3 min, he heard a sound "doe-doe-doe-doe-doe." The dust cloud produced by the fireball was visible for about 10–15 min and drifted during that time, initially at azimuth 285° (from true North, measured by compass and corrected for magnetic declination +2°55′) and elevation approximately 30°. The azimuth direction of the end point was well defined by distant buildings. Elsewhere at Station 6 (20°45.040′N; 32°32.861′E), we spoke with truck driver Omar Fadul El Mula, who had spent the night at Station 6 during the fall. During morning prayer under the overhang of the shelter and before the end of the prayer, he saw a gush of a very strong light that lit up the landscape. The light was terminated by a massive explosion. He rushed outside and saw a cloud in the sky that gradually broke up, in a direction 35–40° elevation and 296° azimuth, slightly north from west (from magnetic north). A "kud-kud" sound was heard 2–3 min after the light. A colleague, El Sayed El Zani Abam (20°45.207′N; 32°32.946′E) was just about to wake for morning prayer when Omar pointed out how light the scenery had become. He, too, stepped outside of the overhang and saw the smoke cloud in the sky, at 281° azimuth and about 40° elevation. He reported hearing a sound described as "dud-dud-dud." He reported seeing a star that went over his head toward the East, but only just after hearing the sound. We suspect that this was a satellite. We concluded that the trajectory of the fireball had ended relatively high in the atmosphere, consistent with the 37 km point reported by the U.S. government satellites, and no large fragments had emanated from the fireball.

At Wadi Halfa, we spoke with station attendant Omer Elhag Abdelgadir, who obtained a short cell phone video record of the train. He saw the fireball at around 2:43:28 UTC (as recorded by the phone, time not checked or corrected) while walking back from the mosque, about to open the front door of his house. He saw a bright light, as if rushing behind him, thinking a car was approaching. He turned and saw the fireball becoming brighter while it came down, and feared it might be a rocket. Compared to distant land marks, the video images implied that the train was at azimuth approximately 161°, drifting east. The fireball and train were also seen by his mother, who saw the courtyard light up and could follow the train until sunrise, when it disappeared. Another brief cell phone video was obtained by Mohamed Mubarak Abdelateef from elsewhere in Wadi Halfa at about the same time.

At the Wadi Halfa train station itself, Mohammed Elhassan Abdelatif Mahir took the now well-known image of the train (featured as the Astronomy Picture of the Day on November 8, 2008) from 21°48.212′N, 31°20.398′E (187 m elevation). Using a compass, the azimuth direction of the lowest and brightest part (red from the rising sun) was determined at between 152° and 154° from true north. Six images of the train were obtained during the short time interval from 03:24 to 03:27 UTC, when the rising sun illuminated the dust cloud against a still dark twilight sky.

In the evening of December 4, we made star background images from the perspective of one of the observers at Wadi Halfa, Mr. Hashim Mahir, who had

Fig. 2. Members of the first search team pose for a group photo at Station 6 on December 8, 2008, shortly after the successful recovery of 2008 TC_3.

captured the persistent train using a cell phone from his courtyard (21°47′22.7″N, 31°23′27.1″E, 189 m elevation) at 03:24:17 ± 30 s UTC. The photo showed a fence with foreground objects placed against it (still in place at the time of the measurement) and a background building with telephone or electricity wires at some distance. The wires proved helpful in reconstructing the exact perspective. From these images, the azimuth and elevation of the train were reconstructed, putting the cloud between azimuth 152° and 156°, in good agreement with other observers (Fig. 3).

The result is compared to that predicted by the UK Meteorological Office (UKMO) wind model (Swinbank and O'Neill 1994) for the prevailing vertical wind profile over the 50 km trajectory point at 0 h UT on that day (Fig. 4). Overall, the UKMO model seemed to represent the observations well, but has much less altitude resolution than what was manifested in the shape of the train. Indeed, the UKMO model is based on smoothed radiosonde profiles to remove the real short-period fluctuations in temperature and wind speed, without gravity wave perturbations. The UKMO model profiles should be thought of as broadly averaged profiles crudely representing a specific geographical region averaged over time.

Interestingly, the main explosion had occurred in a region of distinct opposite wind direction, which caused the lower part of the dust cloud to drift south, while the remaining train higher up drifted north (Fig. 5). No significant ablation occurred after the main explosion (based on lack of a visible train in the cell phone images at these heights), at least below about 32 km. These results are consistent with those derived from the Meteosat 8 and 9 images by Borovička and Charvát (2009).

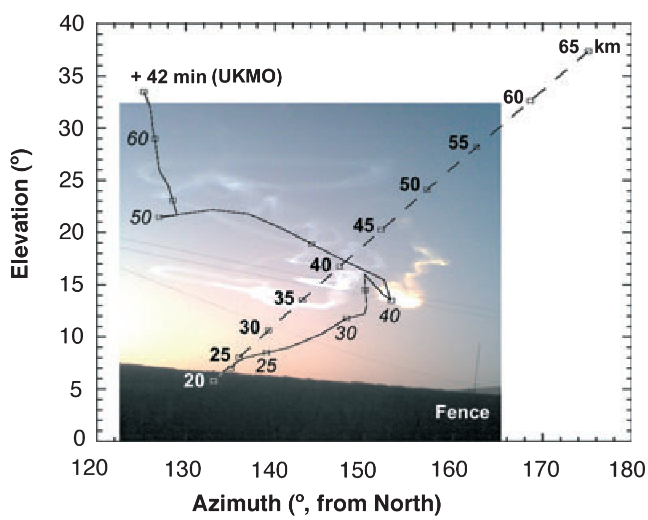

Fig. 3. Dust train as seen from Wadi Halfa +42 min after the fireball. Overlayed is the calculated trajectory of the asteroid and the dust trail as propagated by the UKMO wind model. The part of the train penetrating deepest in the atmosphere is colored red, due to the rising sun as seen from 40 km altitude at that time.

THE METEORITE STREWN FIELD

Once the asteroid had fragmented, individual fragments fell to the Earth under the influence of gravity, drag, and high altitude winds, with the smaller

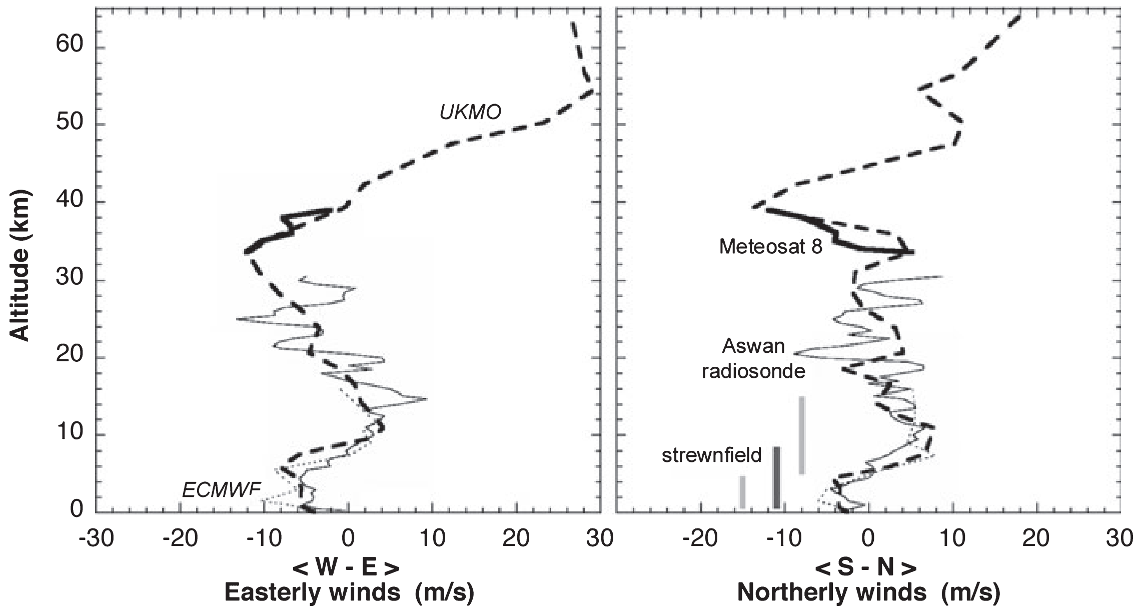

Fig. 4. Vertical wind profiles of easterly (left) and northerly (right) wind speeds according to several sources. The thin solid lines represent the radiosonde data from Aswan, Egypt (23.96°N, 32.77°E) taken at 0 UTC, October 7 (source: University of Wyoming; http://weather.uwyo.edu/upperair/sounding.html; from Borovička and Charvát 2009). The thick dashed line is from the UK Meteorological Office wind model for the 50 km trajectory point at coordinates 20.81°N, 32.34°E on October 7 at 12 h UTC, the thin dashed line is data from the ECMWF wind model on October 7 at 0 h UTC. The thick solid line at heights around 35 km is the wind profile needed to reach agreement with the observed Meteosat 8 dust cloud position at 3:38.8 UTC (Borovička and Charvát 2009). The thick solid vertical bars at low elevation is that required to explain the location of the meteorite strewn field (see text).

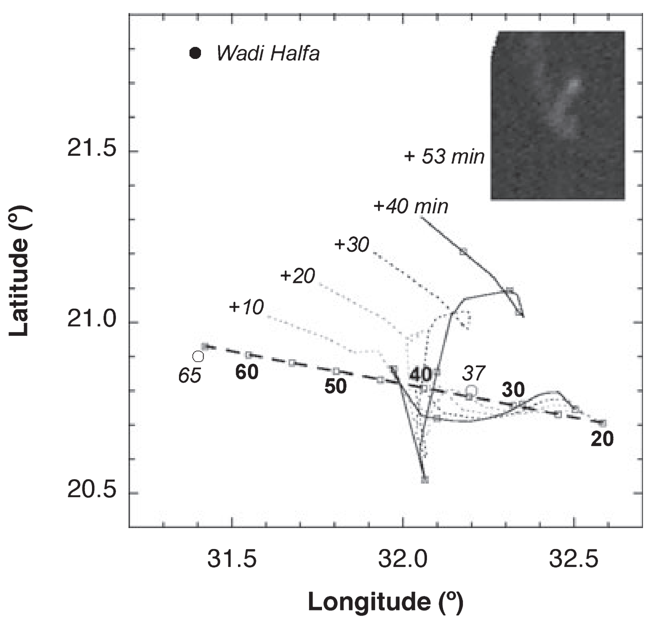

Fig. 5. Dust train motion calculated from the UKMO model (Fig. 4) as seen projected on the surface. Open circles are the positions reported by U.S. Government satellites. Inset: Meteosat 9 detection of the brightest part of the train (around 37 km altitude) on the same scale at 03:38.8 UT. This image is from Borovička and Charvát (2009), after projection on a rectangular coordinate grid.

fragments with higher surface-to-mass ratio more affected by wind than the larger pieces. As a result, the small fragments fall to the ground close to the point of fragmentation, whereas the larger fragments continue to travel onward and fall further down track. If the fragmentation point is at high altitude, the winds have much greater influence on their dark flight and the fragments can drift considerably tangential to the trajectory depending on the prevailing wind conditions at that time. Based on the lack of a train of fragments seen postexplosion, we concluded that any surviving fragments had to be small.

The small fragment size and the large dispersion made searches by car ineffective. Instead, we brought a large team of students and staff of the University of Khartoum to the search area. Individuals were lined up 10–30 m apart to comb the desert systematically (Fig. 6). The general walking direction was maintained by a few observers who carried *Garmin eTrex Vista HCx* handheld GPS receivers. When a meteorite was found, each observer was to signal the collectors (P. J. and M. H. S., later also M. A. or J. H.) and not touch the stone. The geographic location of each sample was recorded as was the name of the finder, and pictures were taken in many cases of the meteorites in situ (with GPS next to it) and the finders. The samples were collected in

Fig. 6. Search strategy. M. H. S. gives the start signal for the team to proceed searching in a gravely area typical of the low-mass end of the strewn field. This scene is from the fourth search.

aluminum foil, carried in a backpack and stored in a plastic or cardboard container.

Search campaigns were organized on December 6–8, 2008 (45 participants—1, 4, and 10 finds on each of the days, respectively) and December 26–30 (72 participants—0, 0, 2, 4, and 29 finds), the results of which are given in Table 2. These searches were followed up on 2009 February 27–March 02 with 54 participants (0—due to a sandstorm, 7, 112, and 95 finds) and 2009 December 9–12 with 74 participants—0, 26, 290, and 8 finds (see Table 3). In all, about 150 individuals participated in the searches, finding on average about four meteorites per person (with actual rates varying from 0 to 38 per person) and about 0.7 meteorites per person per day of searching. The number of finds in the later searches (Table 3) is approximate, as some finds were only the size of a grain of sand, and some doubtful finds may turn out to not to be meteorites. Many meteorites were found in pairs and multiples.

The search consisted of surveys along the estimated ground track (east–west), as well as three surveys tangential to the track in sandy plains near the predicted impact points of 100, 10, and 1 g meteorites after falling from 37 km altitude (from now on the "100, 10, and 1 g points"). The dispersion of meteorites found tangentially relative to the calculated trajectory is summarized in Table 4. These three cross-track surveys are discussed below.

The search area around the 100 g point consisted of a sandy plain with course gravel about 6 km on both sides from the railroad. This area contained the larger fragments (ranging from a few tens of grams to 379 g). Away from the railroad, this terrain changed into small hills with more coarse gravel and rocky outcrops (Fig. 6), leading up to a ridge of hills just east of Marble Mountain. Most gravel was colored lighter and was more angular in shape than the recovered meteorites. Closer to the hills, there were frequent rock outcrops. Just behind the hills was a sandy plain, a region where about 10 g pieces were found. Further west, this terrain gradually became hillier again, with the size and frequency of gravel and rock outcrops increasing until the search area reached a high ridge of hills (seen as an arc in Fig. 1).

The meteorites recovered in the first two searches (Table 2) are the topic of papers published elsewhere in this issue. The location of finds from the first search is shown in Fig. 7. One along-track search was performed, with searchers spread out along a line of about 0.5 km, perpendicular to and in between the two roads created to guide the support vehicles. The southern sandy road, referred to as "asteroid track," was the more accessible and was used to drive the bus to the search area. Fragment #15 was found outside this band, near the location of the bus.

Most large masses were recovered in the second survey on December 26–30, 2008, just south of the asteroid path (Fig. 8). Much effort was devoted to finding even larger masses east of the railroad, but none were found in the area searched (Fig. 9). The meteorite positions reported on the third and fourth day were later found to be in error (not included in Fig. 8). They were determined by students not well trained in the use of handheld GPS systems. Positions from December 30 are reliable in most cases.

The Cross-Track Surveys

Two ground search traverses perpendicular to the estimated ground track were performed in the third search to determine the cross-track distribution of meteorites. Figure 8 shows the results from the cross-track survey at the 100 g point. A 4 km wide area was searched from near Station 6 to 7 km south of the estimated ground track. The terrain was sandy and flat, with scattered light-colored gravel, providing a near-constant collection efficiency from one place to the next. No further fragments were recovered from the area surveyed during the first (circles) and second surveys (squares), which suggests that the collection efficiency was relatively high. However, two large meteorites were found only after the region was surveyed, including the largest recovered fragment of Almahata Sitta (Fig. 10),

Table 2. Almahata Sitta meteorite finds from December 2008 expeditions.

UOK #	Mass (g)	Latitude (°) WGS84	Longitude (°) WGS84	Elevation (m)	Density (g cm^{-3})	+/−	Class[a]	Type	Notes	Finder
December 6, 2008[b]										
1	4.412	20.76818	32.29267	495	1.77[c]	+1.08/−0.39	2	Ureilite	Thick crust, layered	Mohammed Alameen
December 7, 2008[d]										
3	5.938	20.75994	32.33978	495	2.09	+1.09/−0.41	1	Ureilite		Lu'ie Ahmed Ibrahim
4	14.592	20.75983	32.34792	492	2.55	+0.61/−0.26	1	Ureilite		Aala Eldin Abdelhari
4a	2.616	20.75983	32.34792	492	–	–	1	Ureilite		Aala Eldin Abdelhari
5	10.922	20.75347	32.36764	493	2.65	+0.91/−0.38	?	–	Oriented, fully crusted	Huda Mohamed Yahya/Ismail Salih Araki
6	7.981	20.75583	32.36508	493	1.59	+0.44/−0.19	1	Ureilite		Marwah Mhgoub Bakri
December 8, 2008[d]										
7	1.520	20.75183	32.37366	519	–	–	2	Ureilite		M. Salah Abdelrahman
8	6.934	20.74397	32.39822	489	1.79	+0.66/−0.27	–	?		Margaret Calidakis
9	33.678	20.74164	32.42378	491	3.04	+0.34/−0.16	7	?		Abdelrahman A. Hassan
10	15.858	20.74086	32.42472	490	2.47	+0.52/−0.23	5	Ureilite		M. Salah Abdelrahman
11	17.842	20.74086	32.42472	490	2.59	+0.51/−0.23	1	Ureilite	2.76 g cm^{-3} in H_2O	M. Ibrahim Abelallah
12	9.697	20.73942	32.42572	496	3.43	+1.80/−0.67	–	?		Abdelmahmoud Osman
13	32.148	20.73672	32.43758	486	2.88	+0.33/−0.15	3	?	Oriented, fully crusted	M. Yousif A. Eltayeb
14	152.580	20.72925	32.49067	478	2.76	+0.18/−0.09	4,1	?		Abdelrahman A. Hassan
15	75.536	20.72233	32.49639	473	3.11	+0.14/−0.07	1	Ureilite	APOD	Seif Eldin M. Gasmallah
16	171.080	20.72228	32.52617	465	3.40	+0.24/−0.11	5	EH6		M. Hamad Adam
December 28, 2008[d]										
17	4.885	–	–	–	1.67	+0.85/−0.32	6,5	?	At top of hill	Abdel Razig
18	42.790	–	–	–	2.99	+0.26/−0.12	3	–		Diyaa Numan
December 29, 2008[d]										
19	4.859	–	–	–	1.75	+1.29/−0.43	1,3	Ureilite	Part of sample 21	Abdel M. Osman
20	7.989	–	–	–	2.36	+0.50/−0.22	5,7	Ureilite		M. Saaeed Sultan
21	127.230	–	–	–	2.99	+0.26/−0.13	4,1	Ureilite		Sana Yahia
22	115.320	–	–	–	3.24	+0.35/−0.17	3	?		Saadia Elsir Satiri
December 30, 2008[d]										
23	3.681	20.70684	32.50947	466	1.65	+1.15/−0.39	–	Ureilite	70 m from his "10"	Mohammed Alameen
24	92.760	20.70862	32.50882	467	2.72	+0.31/−0.15	4	Ureilite		Mohammed Alameen
25	221.950	20.71546	32.52788	469	–	–	6	H5		Mohammed Almofty
26	3.921	20.70682	32.50882	466	1.63	+1.04/−0.37	5,7	?	Similar to 16	Khalid Mabrook
27	283.840	20.71727	32.50961	470	2.82	+0.07/−0.03	1	Ureilite		Diyaa Numan
28	32.131	20.70889	32.52025	467	2.57	+0.25/−0.12	1	Ureilite	Fragment	Wasil
29	55.417	20.70810	32.51801	467	2.81	+0.16/−0.07	3	Ureilite		Awad
30	170.510	20.70830	32.50951	467	3.10	+0.20/−0.09	1	?	Fully crusted	Razan

Table 2. *Continued*. Almahata Sitta meteorite finds from December 2008 expeditions.

UOK #	Mass (g)	Latitude (°) WGS84	Longitude (°) WGS84	Elevation (m)	Density (g cm^{-3})	+/−	Class[a]	Type	Notes	Finder
31	88.796	20.70492	32.51180	465	2.96	+0.09/−0.05	1	Ureilite		Anas Mohammad
32	130.400	20.70178	32.49670	464	2.96	+0.26/−0.12	3	Ureilite	Multiple fractures	Beder Eldien
33	76.444	20.70966	32.50787	464	4.85	+0.39/−0.17	–	?	Unrelated to A.S.?	Ahmed Elhadi
34	32.985	20.70178	32.49690	464	2.71	+0.28/−0.13	–	Ureilite	Part of 39	Beder Eldien
35	99.604	20.71758	32.51118	470	3.23	+0.10/−0.05	3	?		Tamir Abel Alarir
36	57.880	20.71195	32.51850	469	2.67	+0.14/−0.06	3	Ureilite		Beder Eldien
37	155.080	20.71496	32.50326	469	–	–	3	Ureilite		Amir Sousou
38	237.300	20.71747	32.49371	470	3.12	+0.13/−0.06	3	?		Abdel Rahman
39	5.661	20.70178	32.49670	464	–	–	5	Ureilite	Has fallen apart	Beder Eldien
40	7.976	–	–	–	2.37	+1.02/−0.40	1	Ureilite	In camera	M. Saaeed Sultan
41	84.331	20.71025	32.50994	467	3.16	+0.12/−0.06	7	EL6	Fine grained	Anas Mohammad
42	72.092	20.71383	32.49993	469	2.95	+0.12/−0.06	1	Ureilite		Mohammed Salah
44	2.291	20.70178	32.49690	464	–	–	–	Ureilite	Small fragments in sand	Beder Eldien
46	162.147	20.71169	32.51803	468	2.82	+0.17/−0.08	5	Ureilite		Mohammed Salah
47	25.312	–	–	–	2.96	+0.44/−0.21	3	Ureilite	Numerous pieces	–
48	152.110	–	–	–	2.88	+0.19/−0.09	4,1	Ureilite	Picked out of sand	–
49	61.149	20.70684	32.50882	466	–	–	1	Ureilite	One of 10 pieces	Mohammed Alameen
49a	10.100	20.70684	32.50882	466	–	–	–	Ureilite		Mohammed Alameen
49b	6.670	20.70684	32.50882	466	–	–	–	Ureilite	Part of his "10" pieces	Mohammed Alameen
49c	4.710	20.70684	32.50882	466	2.55	+2.66/−0.75	–	Ureilite	10 m from 10 pieces	Mergani
50	25.312	20.71603	32.48170	469	2.37	+1.49/−0.52	3	–	Part of 47?	Eimad Eldein
51	20.197	20.71546	32.52788	469	2.70	+0.49/−0.22	2	Ureilite	Breccia	Sana Yahia
52	8.023	–	–	–	2.57	+0.53/−0.23	4	Ureilite		–
53	95.342	–	–	–	2.40	+0.23/−0.11	3	Ureilite		–
54	121.220	–	–	–	2.57	+0.20/−0.09	3	Ureilite		–

[a]Class refers to seven different meteorite textures as shown by meteorites #27 (1—scruffy, black), #7 (2—porous, layered), #22 (3—gray, course, bubbly), #24 (4—gray, course, large grains), #16 (5—gray, fine grained), #25 (6—light colored, chondrules), and #41 (7—light gray, fine grained, like concrete).
[b]Collected by P. Jenniskens.
[c]X-ray tomography of sample gave density of 1.485 g cm^{-3}.
[d]Collected by M. H. Shaddad.
[e]X-ray tomography of sample (Fig 16) gave density of 3.09 g cm^{-3}, but uncertain value.

Table 3. Almahata Sitta meteorite finds from 2009 expeditions.

UOK #	Mass (g)	Latitude (°) WGS84	Longitude (°) WGS84	Elev. (m)	Class	Type	Notes	Finder
Between searches								
55	200.420	20.73008	32.51421	481	4	–	Uncertain location	Sadig (mechanic)
56	–	20.72641	32.48502	477	–	–	Wadi Jabal Umfitfit (stomach of the lamb valley)	Camel boy (reported by Sadig, location approximate)
February 28, 2009[a]								
57	221.570	20.70315	32.51273	468	7	–		Mohamemd Taha
58	303.690	20.68662	32.52056	466	6	–		Mariam Nizal Yousaf
59	60.174	20.73654	32.48991	474	5	–		Dr. Salih Ali Salih
60	76.999	20.69704	32.49983	462	1,6	–		Diyaa Numan
61	259.860	20.69704	32.50231	457	6	–		Peter Jenniskens
61A	36.104	20.69704	32.50231	457	6	–		Peter Jenniskens
62	378.710	20.68123	32.49664	452	1	–		Peter Jenniskens/ Abdrahahim Hamdan
62A	4.600	20.68120	32.49664	452	1	–		Nedal Faisal
63	44.262	20.69926	32.49034	459	3	–	Crusted	Wasil
March 01, 2009[a]								
64	12.746	20.75409	32.36274	494	–	–	Doubtful (terrestrial), fully crusted	Bader Aldeen Musa/ Mohammed Ali
65	5.648	20.75012	32.36339	495	6	–		Ismail Salih Araki
66	65.733	20.74459	32.35703	488	4	–		Husein M. Osman
67	17.157	20.73656	32.35614	488	4	–		Esam O. Awdullah
68	0.265	20.73769	32.36253	484	5	–		M. Ali Yousif
69	8.490	20.73631	32.36378	484	3	–		Anas Mohammad
70	11.559	20.73342	32.36379	482	6,5	–		Reem Crasim
71	2.665	20.73338	32.36377	482	4	–		Mowada Ibrahim
72	7.503	20.73294	32.36372	842	5	–	Big one	Mowada Ibrahim
73	5.918	20.73640	32.36730	482	7	–	Crusted	–
74	4.802	20.73503	32.36593	482	5,3	–		–
75	3.841	20.73422	32.36685	482	3	–		–
76	8.072	20.73407	32.36647	480	4	–		Tahani Shatir
77	3.642	20.73418	32.36647	479	4	–		Diyaa Numan
78	5.176	20.73402	32.36685	480	1,7	–		Tahani Shatir
79	6.838	20.73460	32.36599	482	6	–		Diyaa Numan
80	3.781	20.73420	32.36648	480	6	–		Ismail Salih Araki
81	1.971	20.73410	32.36648	480	6	–		Ismail Salih Araki
82	0.294	20.73758	32.36462	476	5	–		Jamal Abdullah
83	3.247	20.73778	32.36460	476	6	–		Ali Eisawi
84	2.752	20.73450	32.36672	482	1	–		Tahani Shatir
85	6.036	20.73417	32.36713	482	4	–		Peter Jenniskens
86	2.330	20.73272	32.36063	485	1	–		Peter Jenniskens
87	2.690	20.73303	32.36039	486	4	–		Ahmed Elias
88	7.953	20.73372	32.35539	490	3,1	–		Dr. Sadeh/Mohamed Alameen
89	0.265	20.73342	32.35492	496	1	–		Abdalhy Muhammed
90	4.808	20.73345	32.35473	491	–	–	Fully crusted	Mohammed Alameen
91	8.573	20.73357	32.35464	493	–	–	Fully crusted	Ahmed Tejani
92	1.693	20.73367	32.35424	491	6	–		Abdalhy Muhammed
93	17.621	20.73419	32.35419	492	2,6	–		Salih Ali Salih
94	10.260	20.73537	32.35324	494	6	–	Crusted	Salih Ali Salih
95	3.209	20.73482	32.35396	491	3	–	Many small pieces	Mohammed Alameen
96	3.449	20.73266	32.35392	488	5	–		Mohammed Alameen
97	15.640	20.73260	32.35398	487	3	–	Crusted	Mohammed Alameen
98	2.168	20.73263	32.35397	487	2	–		Mohammed Alameen
99	2.100	20.73271	32.35375	487	4	–		Adbalmeaz M.

Table 3. *Continued.* Almahata Sitta meteorite finds from 2009 expeditions.

UOK #	Mass (g)	Latitude (°) WGS84	Longitude (°) WGS84	Elev. (m)	Class	Type	Notes	Finder
100	2.726	20.73273	32.35368	486	3	–		Abdalheaz M.
101	18.188	20.73175	32.35450	481	–	–	Fully crusted	Suhaila Trofig
102	0.996	20.72921	32.36591	475	–	–	Fully crusted	Mohammed Siraj
103	2.644	20.72937	32.36581	473	–	–	Fully crusted	Ebthal Ahmed
104	9.093	20.72931	32.36575	475	6	–		–
105	6.425	20.72766	32.36638	474	5,6	–		Ismail Salih Araki
106	9.025	20.72396	32.36464	471	7	–		Sarah Salah
107	11.284	20.73366	32.36683	470	1,6	–	When bus in sand	–
March 01, 2009[b]								
S48	8.456	20.73422	32.36263	483	–	–		Mohammed Elyas
S49	7.640	20.73392	32.35900	483	5	–		Ashraf Mohamed
S50	17.347	20.73400	32.35775	483	1	–		Salih Ali Salih
S51	–	20.73382	32.35665	484	1	–	Crusted	Salih Ali Salih
S52	1.720	20.73407	32.35618	485	7	–		Salih Ali Salih
S53	5.850	20.73477	32.35660	484	–	–	Fully crusted	Wasil
S54	0.560	20.73467	32.35730	484	7	–		Wasil
S55	1.070	20.73502	32.35658	486	3	–		Wasil
S56	3.669	20.73512	32.35650	485	4	–	Oriented	–
S57	3.150	20.73503	32.35641	485	4	–		Mohammed Taha
S58	1.490	20.73498	32.35590	486	4	–		Wasil
S59	6.880	20.73483	32.35583	486	7	–		Wasil
S60	12.690	20.73440	32.35572	484	1	–		Shedad A. Tijane
S61	3.300	20.73443	32.35565	486	4	–		Wasil
S62	4.780	20.73473	32.35507	489	–	–	Fully crusted	Wasil
S63	1.363	20.73463	32.35408	491	1,3	–		Wasil
S64	8.070	20.73437	32.35392	489	–	–	Fully crusted	Abdulah Elhay
S65	1.126	20.73437	32.35385	489	7	–		Mohammed Alameen
S66	3.290	20.73442	32.35382	489	7	–		Zaeem
S67	0.741	20.73443	32.35378	489	1	Ureilite		Mohammed Amin
S68	2.080	20.73118	32.35822	479	4	–		Ayman Kudoda
S69	23.427	20.73542	32.36903	480	4	–		Diaa Eldin
S70	27.594	20.73517	32.36850	479	5,1	–		Diaa Eldin
S71	–	20.73472	32.36795	479	6	–	Oriented	Diaa Eldin
S72	7.840	20.73462	32.36772	480	–	–		Diaa Eldin
S73	5.810	20.73472	32.36767	480	5	–		Diaa Eldin
S74	–	20.73483	32.36743	479	1	–	Position wrong?	Diaa Eldin
S75	16.030	20.73475	32.36737	481	6	–	Position wrong?	Ayman Kudoda
S76	4.792	20.73458	32.36783	480	6	–	Smooth	Ayman Kudoda
S77	8.072	20.73468	32.36798	479	5	–		Ayman Kudoda
S78	5.065	20.73463	32.36812	479	4	–		Dr. Jamal
S79	2.290	20.73470	32.36828	479	7	–		Tahani Shatir
S80	6.838	20.73435	32.36778	478	–	–	Fully crusted	Tahani Shatir
S81	3.813	20.73420	32.36770	478	–	–	Fully crusted	Mohammed Taha
S82	10.288	20.73352	32.36735	477	2	Ureilite		Dr. Ali
S83	–	20.73278	32.36703	478	–	–	Fully crusted	Ismail Salih Araki
S84	3.247	20.73277	32.36690	477	3	–	Crusted	Ismail Salih Araki
S85	2.540	20.73277	32.36688	478	4	–		Tijane Berlome
S86	2.752	20.73262	32.36643	479	–	–	Fully crusted	Ismail Salih Araki
S87	10.364	20.73253	32.36693	479	–	–	Fully crusted	Diaa Eldin
S88	6.946	20.73233	32.36720	478	–	–	Fully crusted	Ibtihal
S89	28.063	20.73193	32.36763	478	4	–		Ibtihal
S90	1.925	20.73182	32.36732	478	6	–		Assam Omer
S91	5.010	20.73175	32.36717	478	–	–	Fully crusted	Nuha Mohamed
S92	7.829	20.73188	32.36690	478	5	–		Nuha Mohamed
S93	3.100	20.73165	32.36655	479	–	–	Fully crusted	Nuha Mohamed

Table 3. *Continued.* Almahata Sitta meteorite finds from 2009 expeditions.

UOK #	Mass (g)	Latitude (°) WGS84	Longitude (°) WGS84	Elev. (m)	Class	Type	Notes	Finder
S94	3.816	20.73152	32.36662	477	6	–		Melak
S95	37.702	20.73098	32.36708	478	1	–	Many small pieces	Zaytona
S96	6.125	20.73107	32.36735	479	4	–	Crusted	Mehasin
S97	5.140	20.73042	32.36767	478	4	–		Mehasin
S98	3.229	20.73047	32.36687	478	–	–	Fully crusted	Diaa Eldin
S99	7.873	20.73062	32.36652	478	–	Ureilite		Diaa Eldin
S100	1.545	20.73060	32.36627	477	7	–		Mohamad S.
S101	3.870	20.73077	32.36675	478	3,7	–		Melak
S102	4.030	20.73033	32.36642	477	4	–		Mohamad S.
S103	6.571	20.73038	32.36635	477	3	–	Crusted	Mohamad S.
S104	16.552	20.73010	32.36595	478	6	–		Mohamad S.
S105	6.706	20.72917	32.36682	476	6	–		Ismail Sali Araki
S106	7.032	20.72943	32.36595	475	6	–	Fully crusted	Moez
S107	5.830	20.72672	32.36555	475	–	–	Fully crusted	Melak
S108	8.456	20.72550	32.36590	472	3,6	–		Muzimil Awad
S109	11.312	20.72550	32.36590	474	4	–		Beder Eldien
S110	2.682	20.72547	32.36590	474	4	–		Ahmed Isam
S111	6.741	20.72475	32.36538	474	1	–		Fatima
S112	4.989	20.72467	32.36557	474	3	–	Fully crusted	Omima Osman
S113	10.035	20.72443	32.36502	474	–	–	Fully crusted	Azza Mohsin
S114	–	20.72367	32.36438	474	–	–		–
S115	–	20.72368	32.36437	473	–	–		–
March 02, 2009[c]								
172	8.815	20.74400	32.36157	488	–	–	2 pieces, doubtful	Muawia H. Shaddad
174	28.447	20.74152	32.36067	487	2	–	Crusted	–
175	52.333	20.74158	32.36067	486	4	–	One big, 2 small	Abd Alraheem
175a	0.306	20.74158	32.36067	486	–	–		Abd Alraheem
176	2.035	20.74060	32.36053	486	2	–		Mohaned Sirag
177	12.233	20.74132	32.36480	486	1,4	–		Gamal Addella
178	2.900	20.73853	32.36083	490	–	–	Fully crusted	Alfadil Omer
179	3.557	20.73868	32.35978	493	6	–		Mohammed Taha
180	0.276	20.73847	32.35980	491	6	–		Abdeen
181	2.585	20.73778	32.36117	488	–	–	Fully crusted	Husein M. Osman
182	–	20.73665	32.36038	490	1,7	–		Alfadil Omer
183	3.318	20.73637	32.36043	489	1	–		Alfadil Omer
184	9.407	20.73657	32.35863	490	4	–		Salih Ali Salih
185	4.943	20.73613	32.35888	491	1,7	–	Big and small piece	Abd Almeaz
186	14.509	20.73600	32.35877	487	6	–		Abd Almeaz
187	2.946	20.73568	32.35847	487	5	–		Mohammed Alameen
188	5.066	20.73497	32.35860	485	4	–		Esam O. Awdullah
189	3.481	20.73495	32.35862	486	–	–	Fully crusted	Esam O. Awdullah
190	1.680	20.73465	32.35912	485	4	–		Omima Osman
191	–	20.73440	32.35857	485	8	–	Like 8, different in metals	Esam O. Awdullah
192	2.366	20.73452	32.35805	486	6	–		Salih Ali Salih
193	5.065	20.73388	32.35847	484	–	–	Fully crusted	Mohamed Ali
194	2.764	20.73203	32.36122	484	–	–	Fully crusted, glazed on one side	Muzimil Awad
195	2.380	20.73187	32.36008	486	4	–		Husein M. Osman
196	4.137	20.73127	32.35913	486	4	–		Mohaned Sirag
197	0.694	20.73133	32.35830	484	6	–		Mohammed Taha
198	6.361	20.73298	32.35660	486	6	–		Salih Ali Salih
199	0.522	20.73253	32.35672	485	–	–	Fully crusted	Mohammed Alameen
200	2.921	20.73053	32.35677	486	–	–	Fully crusted	Abd A. Abd Alaziz
201	2.747	20.72510	32.35817	487	6	–		Alfadil O./Omima/Mohaned

Table 3. *Continued.* Almahata Sitta meteorite finds from 2009 expeditions.

UOK #	Mass (g)	Latitude (°) WGS84	Longitude (°) WGS84	Elev. (m)	Class	Type	Notes	Finder
202	20.057	20.71970	32.35957	478	4	–		Mawada Ibrahim
203	16.088	20.71847	32.35175	487	–	–	Fully crusted	Abd A. Abd Alaziz
204	8.334	20.73540	32.36865	483	7	–		Sahba Yahya
205	12.856	20.73643	32.36988	483	6	–		Omer Altahir
206	6.364	20.73652	32.37029	483	6	–		Mohammed Ibrahim
207	12.914	20.73652	32.37029	482	4	–		Mohammed Ibrahim
209	35.470	20.73650	32.37029	482	4	–	Piece 1	Mohammed Ibrahim
209a	20.101	20.73650	32.37029	482	–	–	Piece 2	Mohammed Ibrahim
209b	66.318	20.73650	32.37029	482	–	–	8 pieces	Mohammed Ibrahim
210	3.584	20.73648	32.37072	483	1	–		Omer Altahir
211	14.372	20.73717	32.37105	484	1	–		Marwa Hahgob
212	6.867	20.73685	32.37128	484	4	–		Fatiima Ahmed
213	5.692	20.73505	32.37248	483	–	–		Ahmed Esam
214	3.648	20.73480	32.37327	484	7	–		Mawada Ibraihim
215	2.915	20.73508	32.37298	483	4	–		Ahmed Esam
216	6.067	20.73673	32.37368	484	–	–	Fully crusted	Tahani Shatir
218	7.502	20.73617	32.37494	483	–	–	Fully crusted	Sahba Yahya
219	10.072	20.73592	32.37585	484	–	–	Fully crusted	Sahba Yahya
220	5.771	20.73572	32.37580	485	4	–		Ismayel
221	8.418	20.73668	32.37582	484	7	–		Marwa Mahgob
222	20.618	20.73680	32.37605	485	–	–	Fully crusted	Abd Alraheem
225	10.210	20.73637	32.37777	486	4	–		Azza Mohsin
226	13.682	–	–	–	4	–		Mohamed Bakry
227	0.591	20.73538	32.37828	485	–	–	Fully crusted	Mawada Ibrahim
228	21.879	20.73643	32.37888	486	4	–		Marwa Mahgob
229	1.368	20.73540	32.37847	485	–	–	Fully crusted	Mawada Ibrahim
230	1.288	20.73488	32.38060	487	4	–		Ameen Altahir M.
231	5.365	20.73680	32.38468	487	5	–		Ismayel
232	10.412	20.73668	32.38900	479	6	–		Bader Aldeen Musa
233	–	20.73450	32.37488	486	–	–		Abdo
234	20.837	20.73362	32.39102	477	4	–		–
235	7.645	20.73427	32.39668	477	1	–		Nada M. Alameen
236	23.523	20.73573	32.39457	476	6	–		Nada M. Alameen
237	0.571	20.73298	32.40014	476	1	–		Roua Mowaia
238	3.981	20.73298	32.40017	475	4	–		Roua Mowaia
239	28.198	20.73097	32.39747	473	6	–		Omer Altahir
240	1.554	20.73095	32.39747	473	4	–		Mosab Salah -driver
241	23.148	20.73078	32.39853	473	7	–		Sarah Salah
242	23.499	20.73395	32.39910	476	1	–		Ismayel
243	4.561	20.72937	32.40803	477	1	–		Ashraf Mohamed
244	–	20.73572	32.37628	485	–	–		–
245	17.769	20.72925	32.40858	476	4	–		Abd Alraheem
246	7.194	20.72952	32.40885	475	4	–		–
247	57.699	20.73263	32.40357	478	4	–	Glazed	Ebtihal Ahmed
248	6.207	20.73070	32.40680	481	–	–		Omima Osman
249	24.702	20.72897	32.41502	476	6	–		Ebtihal Ahmed
250	3.595	20.72920	32.41597	478	5	–		Hussein Mohamed
251	79.675	20.72963	32.41865	479	3	–		Abdeen Mohamed
252	27.011	20.72890	32.41962	478	4	–		Hoyam Mohamed
253	29.173	20.72570	32.42105	478	1	–		Mohammed Alameen
254	21.736	20.72873	32.42255	481	6	–		Nuha Mohamed
255	13.501	20.72928	32.42162	482	7	–		Marwa Mahgob
256	16.607	20.72583	32.42760	481	5	–		Mohamed Ali
257	1.214	20.72582	32.42762	481	–	–	Fully crusted	Mohamed Ali
258	0.235	20.72582	32.42762	481	–	–	Fully crusted, black	Mohamed Ali
260	41.904	20.72350	32.43827	473	4	–		Abd A. Abd Alaziz

Table 3. *Continued.* Almahata Sitta meteorite finds from 2009 expeditions.

UOK #	Mass (g)	Latitude (°) WGS84	Longitude (°) WGS84	Elev. (m)	Class	Type	Notes	Finder
261	109.899	20.71388	32.46920	468	–	–	During car search	Tahani Shatir
262	15.045	–	–	–	–	–	Fully crusted	Dr. Saleed
March 02, 2009[c]								
S116	4.829	20.74400	32.36153	486	–	–		Mohaned M.
S117	54.078	20.74148	32.35985	486	4	–		Wasil
S118	19.535	20.74118	32.35954	485	1	–		Abd A. Abd Alaziz
S119	1.606	20.74052	32.36148	484	–	–		Ashraf Mohamed
S120	5.230	20.73938	32.36230	485	1	–		Muzimil Awad
S121	4.759	20.73567	32.36698	485	6	–		Uz. Fatma
S122	15.878	20.73463	32.36497	484	3	–	Smooth	Anas Mohammad
S123	6.536	20.73287	32.36757	479	–	–		Nuha Mohamed
S124	7.782	20.73362	32.36180	485	1	–		Muzimil Awad
S125	3.519	20.73307	32.36033	482	–	–		Hussein
S126	5.488	20.73503	32.36080	484	–	–		Wad Elyas
S127	20.667	20.72890	32.36685	479	4	Ureilite		Sarah Salah
S128	7.490	20.72663	32.36448	479	1	–		Sahba Yahya
S129	9.321	20.73095	32.36397	479	4	Ureilite		Ismail Salih Araki
S138	2.812	20.73537	32.36740	479	7	Ureilite		Esam O. Awdullah
S139	10.317	20.73140	32.36670	477	1	–		Moez
S140	1.373	20.73192	32.36680	479	4	–		Omima Osman
S141	1.076	20.73093	32.36666	478	–	–	Fully crusted, small	Esam O. Awdullah
S142	2.077	20.73093	32.36663	479	5	–		Motasim Adlan
S143	4.852	20.73102	32.36957	480	–	–	Fully crusted	Alfadil
S144	6.182	20.73485	32.37205	481	7	–		Ahmed Esam
S145	6.589	20.73490	32.37203	481	7	–		Nedal Faisal
S146	0.340	20.73435	32.37123	482	–	–	Fully crusted	Muawia H. Shaddad
S146a	4.793	20.73435	32.37123	482	–	–	Fully crusted	Muawia H. Shaddad
S147	5.369	20.73428	32.37123	482	6	–		Muawia H. Shaddad
S148	6.564	20.73433	32.37077	481	5	–		Shaygi
S149	6.786	20.73427	32.37078	481	–	–	Fully crusted	Beder Eldien
S150	9.143	20.73415	32.37110	481	–	–	Fully crusted	Moatsim Adlan
S151	8.310	20.73363	32.36978	482	7	–		Muzimil Awad
S152	9.111	20.73353	32.37008	482	1	–		Muzimil Awad
S153	1.161	20.73203	32.37332	483	–	–	Fully crusted	Hussein
S154	31.636	20.73013	32.37500	485	6	–		Esam O. Awdullah
S155	6.448	20.73043	32.37648	486	1	–		Abdeen
S156	2.873	20.73053	32.37635	486	1	–		Alfadil
S156a	1.394	20.73053	32.37635	486	–	–		Alfadil
S156b	0.920	20.73053	32.37635	486	–	–		Alfadil
S157	–	20.73042	32.37646	484	–	–	Fully crusted	Zaeem
S158	3.432	20.73130	32.37665	485	–	–	Fully crusted	Ashraf Mohamed
S159	2.174	20.73165	32.37660	484	8	–		Hussein
S160	–	20.73448	32.37583	483	4	–		Beder Eldien
S161	7.353	20.73208	32.37883	485	6	–		Hussein
S161a	14.563	20.73208	32.37883	485	–	–		Hussein
S162	5.073	20.73447	32.37758	483	4	–		Beder Eldien
S163	–	20.72970	32.38285	485	1	–		Alfadil
S164	28.821	20.72973	32.38398	483	4	Ureilite		Abdeen
S165	10.814	20.72980	32.38430	484	–	–	Fully crusted	Ashraf Mohamed
S166	10.423	20.73108	32.38443	486	4	–	Approx. coordinate	A. Hay
S167	24.850	20.72680	32.38432	490	–	–		Hussein
S168	2.812	20.73230	32.38417	486	7	–		Mohaned M.
S169	1.422	20.73180	32.38720	480	–	–		–
S170	4.069	20.72950	32.38900	478	3	–		Mohaned Taha
S171	17.259	20.72935	32.38773	479	3	–	Many small pieces	Abdeen

Table 3. *Continued.* Almahata Sitta meteorite finds from 2009 expeditions.

UOK #	Mass (g)	Latitude (°) WGS84	Longitude (°) WGS84	Elev. (m)	Class	Type	Notes	Finder
S172	–	20.72748	32.39052	477	1	–		Esam O. Awdullah
S173	6.710	20.72775	32.39160	477	9	–		Mohamed Sir
S174	–	20.72828	32.39235	477	5	–		Moez
S175	19.405	20.73100	32.39370	478	6	–		Ashraf Mohamed
S175a	6.540	20.73100	32.39370	478	–	–	Fully crusted	Ashraf Mohamed
S176	9.709	20.73110	32.39363	478	3	–		Motasim Adlan
S177	–	20.72803	32.39360	476	3	–		Moez
S178	8.640	20.72985	32.39317	475	4	–		Alfadil
S179	11.194	20.72752	32.39582	474	–	–	Fully crusted	A. Hag
S180	11.841	20.72618	32.39645	473	4	–		A. Hag
S181	5.116	20.72860	32.39530	473	1	–		Omima Osman
S182	–	20.73072	32.39373	474	6	–		Hussein
S183	3.318	20.72765	32.39702	473	5	–		Moez
S184	21.714	20.72798	32.39705	474	1	–		Moez
S185	25.644	20.73270	32.40160	478	1	–		Azza Mohsin
S186	9.407	20.73267	32.40158	478	–	–		Uz. Fatma
S187	7.230	20.73267	32.40162	477	–	–	Fully crusted	Fatima Ahmed
S188	14.509	20.73097	32.39837	475	–	–	Fully crusted	Omima Osman
S189	15.844	20.72665	32.40318	475	1	–		Abde Albsit
S190	3.770	20.73132	32.40977	476	–	–	Fully crusted	Mawada Ibrahim
S191	24.108	20.73143	32.42287	479	5	–		Harhi
S192	13.677	20.72448	32.42437	473	7	–		Abde Albsit
S193	18.024	20.72908	32.41975	476	–	–	Fully crusted	–
S194	82.494	20.73062	32.43620	481	1	–		Alfadil
S195	28.962	20.72298	32.44038	475	4	Ureilite		Abdel Basit
S195a	24.933	–	–	–	1	Ureilite		Abdel Basit
S196	–	20.72610	32.44118	475	–	–	Fully crusted	Moez
S500	4.684	–	–	–	5	–		Mohammed
S501	1.850	–	–	–	–	–		Muhamad M. Shaib
March 02, 2009[b]								
A119	10.0258	20.73006	32.38505	482	–	–		Alfadil Omer
A120	6.6196	20.72982	32.38522	477	–	–		M. Sirag Eldeen
A121	–	20.72966	32.38548	478	–	–		Abdeen Mohamed
A122	–	20.72954	32.38640	478	–	–		Abdel Basit
A123	15.0324	20.73007	32.38664	482	1	–		Alfadil Omer
A124	6.8469	20.72947	32.38695	477	–	–		Omima Osman
A125	12.0706	20.72693	32.39538	471	7	–		Mohamed Alameen
A126	4.9689	20.72643	32.39613	476	–	–		Mohamed Alameen
A127	4.6751	20.72645	32.39656	475	4	–		Mohamed Alameen
A128	6.6738	20.72791	32.40114	477	7	–		Mohamed Alameen
A129	8.0034	20.72773	32.40119	475	–	–		Mohamed Alameen
A130	8.9249	20.72736	32.40409	484	–	–		Mohamed Alameen
A131	12.0633	20.72777	32.40735	481	6	–		Mohamed Taha
A132	15.1522	20.72803	32.40716	479	7	–		Mohamed Alameen
A133	7.5058	20.72882	32.40912	497	5	–		Mohamed Taha
A133A	15.5256	20.72882	32.40912	497	–	–		Mohamed Taha
A134	25.7386	20.72948	32.41057	471	–	–		Mohamed Alameen
A135	8.7259	20.72690	32.41536	477	1	–		Abdel Basit
A135A	63.874	20.72690	32.41536	477	–	–		Abdel Basit
A136	–	20.72566	32.42110	476	–	–		Mohamed Alameen
A137	32.9605	20.72866	32.42738	483	–	–		Malak Ahmed
A138	–	20.72894	32.42796	480	–	–		Abdeen Mohamed
A139	0.9177	20.72901	32.42841	480	7	–		Reem Gasim
A500	–	–	–	–	–	–		Mohamed Alameen
A501	–	–	–	–	–	–		Mohamed Alameen
A502	–	–	–	–	–	–		Abd Elhai

Table 3. *Continued.* Almahata Sitta meteorite finds from 2009 expeditions.

UOK #	Mass (g)	Latitude (°) WGS84	Longitude (°) WGS84	Elev. (m)	Class	Type	Notes	Finder
December 10, 2009[c]								
602	141.842	20.69525	32.48723	459	3	–		M. Ali Yousif
603	17.208	20.70507	32.45083	464	1	Ureilite		Shafir Hashim
604	–	20.71992	32.42762	473	–	–	Doubtful	Wail Achmed
605	34.330	20.72265	32.44070	470	4	–		Akram Moubarrack
606	35.270	20.71505	32.44223	465	4	–		Omar Eltaher Harbi
607	20.889	20.71532	32.44337	466	4	Ureilite		Mohammed Salah
608	74.726	20.72168	32.45177	466	4	–		Chaled Morouk
609	80.128	20.72103	32.45258	466	7	–	Doubtful	Ahmed Adoud
610	71.993	20.71612	32.45235	464	3	–		Mohammed Alameen
611	147.800	20.71137	32.46515	461	3	–		Stefan Loehle
612	87.552	20.73748	32.36485	481	9	–	Doubtful	–
December 10, 2009[a]								
1001	7.700	20.70258	32.48700	463	8	–		Mukthar Mohammed
1002	–	20.70757	32.46910	468	–	–		Horst Uwe Keller
1003	10.800	20.70378	32.45337	461	–	Ureilite		Ismael Sahil Araki
1004	13.500	20.70378	32.45338	461	4	Ureilite		Ismael Sahil Araki
1005	21.300	20.72473	32.42553	475	5			Mohammed Hamad
1006	12.300	20.72627	32.42645	476	3	Ureilite		Tahani Shatir
1007	23.500	20.72535	32.42920	479	3	–		Alla Abdarhaman
1008	23.600	20.72553	32.42972	478	4	–		Loay A. Ibrahim
1009	13.800	20.72535	32.42988	477	7	–		Ahmed Adoud
1010	23.700	20.72110	32.43917	470	4	Ureilite		Frederic Vachier
1011	22.000	20.72070	32.44458	469	8			Esam O. Awdullah
1012	28.700	20.72082	32.45002	468	3	Ureilite		Petr Scheirich
1013	–	20.72037	32.45312	465	4	–		Ismail Sahil Araki
1014	–	20.71353	32.46877	463	6	–		Muzamil Awad
1015	–	20.71937	32.47265	469	3	–		Nur Achmed Atib
December 11, 2009[a]								
1016	5.459	20.73667	32.36485	479	7	–		Mohammed Alameen
1017	4.909	20.73667	32.36485	480	5	–		Mohammed Alameen
1018	0.822	20.73660	32.36492	481	1	–		Mohammed Salah/ Esam Omer
1019	4.909	20.73197	32.36457	483	–	–		Samah Elsir
1020	0.822	20.73223	32.36470	482	7	–		Osama
1021	5.559	20.73543	32.36338	485	1	–		Esam O. Awdullah
1022	8.829	20.73653	32.36400	483	4	–		Jacob Kuiper
1023	7.820	20.73760	32.36283	483	4	–		Ahmed Adoud
1025	4.971	20.73832	32.36378	483	4	–		Sana Yahia
1026	1.138	20.73903	32.36323	483	4	–		Tahani Shatir
1027	3.145	20.73918	32.36280	483	3	–		Adam Daoud Omer
1028	0.603	20.73677	32.35895	486	4	–		M. Alhaj Eltayb
1029	1.164	20.73622	32.35805	485	4	–		Ahmed Isam
1030	11.984	20.73597	32.35798	485	4	–		Bader Aldeen Musa
1031	2.592	20.73542	32.35798	485	–	–		Saadia Elsir Satiri
1032	3.871	20.73575	32.35778	485	4	–		Rana Faroug Badry
1033	0.529	20.73647	32.35720	485	6	–		Esam O. Awdullah
1034	1.272	20.73603	32.35682	487	3	–		Amy Morrow
1035	11.761	20.73552	32.35755	486	4	–		Saadia Elsir Satiri
1036	4.367	20.73552	32.35753	486	3	–		Saadia Elsir Satiri
1037	5.389	20.73728	32.35618	487	1	–		Mohammed Ibrahim
1038	6.533	20.73702	32.35635	487	6	–		Alshfia H. Osman
1039	1.165	20.73652	32.35630	488	3	–		Alshfia H. Osman
1040	10.544	20.73615	32.35585	488	4	–		Francois Colas
1041	14.868	20.73655	32.35578	488	5	–		Alwaleed Ahmed

Table 3. *Continued*. Almahata Sitta meteorite finds from 2009 expeditions.

UOK #	Mass (g)	Latitude (°) WGS84	Longitude (°) WGS84	Elev. (m)	Class	Type	Notes	Finder
1042	16.085	20.73677	32.35530	489	4	–		Mawada Ibrahim
1043	1.555	20.73447	32.35555	489	–	–	Fully crusted	Omima Osman
1044	5.139	20.73502	32.35433	490	3	–		Tomas Kohout
1045	0.810	20.73620	32.35442	491	4	–		Petr Scheirich
1046	8.137	20.73692	32.35480	490	–	–		Omer El-taher Harbi
1047	1.998	20.73900	32.35390	490	4	–		Tamir Abdel Alazir
1048	1.913	20.73975	32.35283	491	6	–		Mukhtar Mohammed
1049	5.193	20.74070	32.35375	489	1	–		Mark Hammergren
1050	7.281	20.74122	32.35312	490	–	–		Tahani Shatir
1051	7.294	20.74083	32.35358	489	1	–		Mark Hammergren
1052	6.769	20.74213	32.35368	489	3	–		Casper ter Kuile
1053	19.336	20.74243	32.35337	488	–	–	Flat disc (oriented)	Elmofti
1054	9.069	20.74188	32.35283	491	4	–		Mahdia I. Morahim
1055	1.826	20.74043	32.35115	497	–	–	Doubtful	Mahmoud M. Ahmed
1056	13.562	20.74202	32.35125	493	4	–		Tahani Shatir
1057	9.351	20.73995	32.34760	488	4	–		Jakub Haloda
1058	10.500	20.73990	32.34752	487	3	–		Moeid Haidar
1059	0.869	20.73973	32.34747	488	4	–		Akram Abadl
1060	1.523	20.73973	32.34747	488	–	–	Fully crusted, doubtful	Akram Abadl
1061	0.776	20.73973	32.34748	487	7	–		Akram Abadl
1062	4.626	20.73897	32.34763	487	3	–		Alfatih H. El-Rasoul
1063	6.563	20.73897	32.34840	490	6	–		Petr Scheirich
1064	2.588	20.73902	32.34842	490	3	–		Tomas Kohout
1065	10.316	20.74202	32.34890	491	4	–		Mahdia I. Ibrahim
1066	3.448	20.74150	32.34762	489	4	–		Ahmed Adoud
1067	2.442	20.74185	32.34755	490	–	–		Ahmed Adoud
1068	5.883	20.74110	32.34973	492	6	–		Tamir Abel Alarir
1069	1.808	20.74112	32.34977	493	5	–		Tahani Shatir
1070	4.387	20.74102	32.34982	493	4	–		Tahani Shatir
1071	1.931	20.74050	32.34845	490	3	–		M. Elhaj Eltayb
1072	1.662	20.73973	32.34805	490	4	–		Omima Osman
1073	2.545	20.74247	32.34760	490	3	–		Tamir Abel Alarir
1074	1.440	20.74248	32.34758	490	4	–		Tamir Abel Alarir
1075	5.907	20.74212	32.34393	489	3	–		Abdel M. Osman
1076	3.180	20.74163	32.34533	491	3	–	Sand sample incl.	Frederic Vachier
1077	4.869	20.74227	32.34170	485	5	–		Mahmoud Mustafa A
1078	4.049	20.74318	32.34050	484	–	–		Mark Hammergren
1079	0.628	–	–	–	3	–		Frederic Vachier
1080	5.087	20.74192	32.33943	484	4	–		Sana Yahia
1081	0.050	20.74162	32.33957	484	–	–	Doubtful	Muhanad M. Shaib
1082	2.910	20.74075	32.33930	484	–	–	Fully crusted	Suhaila Trofig
1083	0.966	20.74098	32.33890	483	4	–		Esam O. Awdullah
1084	8.479	20.74022	32.33892	485	1	–		M. Elhaj Eltayb
1085	1.849	20.74173	32.33787	482	4	–	Doubtful	Frederic Vachier
1086	6.854	20.74032	32.33700	483	3	–		Abd E. Abdelgadir
1087	4.775	20.74035	32.33695	483	4	–		M. Elhaj Eltayb
1088	10.970	20.74008	32.33636	482	–	–		Francois Colas
1089	4.219	20.73895	32.33567	481	1	–		Ghada Hussein
1090	8.187	20.74095	32.33487	482	4	–		M. Elhaj Eltayb
1091	78.201	20.74225	32.32955	482	–	–		Adam Daoud Omer
1092	7.084	20.74267	32.32872	483	4	–		Carl Johannink
1093	4.409	20.74278	32.32805	481	–	–		Alfadil Omer Alfad
1094	2.597	20.74283	32.32803	480	3	–		Alfadil Omer Alfad
1095	9.615	20.74257	32.32508	482	–	–		Esam O. Awdullah
1096	7.343	20.74115	32.32432	482	–	–	Fully crusted	Ghada Hussein

Table 3. *Continued.* Almahata Sitta meteorite finds from 2009 expeditions.

UOK #	Mass (g)	Latitude (°) WGS84	Longitude (°) WGS84	Elev. (m)	Class	Type	Notes	Finder
1097	2.627	20.74115	32.32433	483	4	–		Mark Hammergren
1098	11.143	–	–	–	–	–	Fully crusted	Casper ter Kuile
December 11, 2009[c]								
613	9.402	20.73188	32.36447	482	4	–		Muzimil Awad
614	3.501	20.73227	32.36477	483	6	–		M. Ali Yousif
615	4.831	20.73233	32.36478	483	7	–		Moad Ibrahim
616	6.038	20.73333	32.36423	483	3	–		Ahmed Elias
617	6.462	20.73295	32.36397	481	4	–		Alfad El Omar
618	3.448	20.73233	32.36375	481	–	–		Wail Achmed
619	4.050	20.73248	32.36287	482	6	–		Stefan Loehle
620	1.825	20.73258	32.36195	482	4	–		Omima Osman
621	0.083	20.73460	32.36135	486	–	–	Fully crusted, doubtful	Moeid Haidar
622	3.733	20.73528	32.36143	485	4	–		Moad Ibrahim
623	2.285	20.73913	32.36140	482	3	–	Doubtful	Lucy McFadden
624	10.010	20.73700	32.36077	484	6	–		Carl Johannink
625	6.528	20.73567	32.35885	484	3	–		Amir Sousou
626	3.407	20.73495	32.35808	483	7	–		Frederic Vachier
627	2.573	20.73502	32.35812	483	6	–	Doubtful	Frederic Vachier
628	3.113	20.73447	32.35773	484	7	–		Iba Dayesir
629	2.172	20.73288	32.36045	483	3	–		Ohmeyma
630	3.048	20.73222	32.35718	484	7	–		Oda
631	32.037	20.73238	32.35713	484	6	–		Nada M. Alameen
632	13.985	20.73218	32.35622	484	7	–	Fully crusted	Ibrahim
633	13.592	20.73345	32.35645	485	4	–		Alfad el Omar
633A	–	20.73345	32.35645	485	–	–		Not known
634	5.475	20.73393	32.35678	484	1	–		Tomas Kohout
635	0.784	20.73355	32.35792	483	4	–		Ohmeyma
636	4.272	20.73480	32.35363	490	5	–		Wail Achmed
637	0.454	20.73572	32.35243	491	6	–	Doubtful	Stefan Loehle
638	3.020	20.73640	32.35315	490	4	–		Samah Elsir
639	5.017	20.73645	32.35317	490	3	–		Rehab Abas
640	1.812	20.73735	32.35323	489	3	–		Mohammed Al Hadj
641	1.887	20.73722	32.35240	491	5	–		Moeid Haidar
642	1.480	20.73770	32.35190	492	4	–		Rada Houssein
643	8.131	20.73710	32.35273	492	7	–		Mohammed Al Hadj
644	6.542	20.73657	32.35180	493	–	–	Fully crusted	Francois Colas
645	7.016	20.73613	32.35069	489	8	–		Alfad el Omar
646	14.511	20.73550	32.35050	487	3	–		Luc Bastiaensen
647	9.926	20.73522	32.34630	483	4	–		Nada M. Alameen
648	6.226	20.73532	32.34473	481	7	–		Desir Nubeir
649	14.625	20.73567	32.34509	482	5	–		Nada M. Alameen
650	6.190	20.73560	32.34503	482	1	–		Aimad Aldeen
651	1.884	20.73538	32.34610	483	7	–		Francois Colas
652	6.892	20.73610	32.34853	486	3	–	Doubtful	Mohammed
653	6.856	20.73617	32.34907	487	3	–		Madredeen Ganji
654	6.287	20.73723	32.34838	489	3	–		Alfad el Omar
655	1.266	20.73727	32.34835	489	3	–		Alfad el Omar
656	10.236	20.73732	32.34835	489	3	–		M. Ali Yousif
657	3.851	20.73758	32.34830	490	3	–		M. Ali Yousif/ Madredin Mousa
658	13.389	20.73800	32.34782	489	3	–		Umbid Moli
659	1.525	20.73805	32.35052	489	–	–	Doubtful	Mohammed Alameen
660	3.365	20.73428	32.34493	482	6	–		Luc Bastiaensen
661	3.123	20.73830	32.34397	483	–	–		Abdel Fadeel
662	4.076	20.73843	32.34415	483	6	–		Omar Bal Nega

Table 3. *Continued.* Almahata Sitta meteorite finds from 2009 expeditions.

UOK #	Mass (g)	Latitude (°) WGS84	Longitude (°) WGS84	Elev. (m)	Class	Type	Notes	Finder
663	2.342	20.73843	32.34415	483	6	–		Abdel Fadeel
664	1.324	20.73835	32.34423	483	–	–		Ekram
665	1.300	20.73857	32.34438	483	3	–		Moeid Haidar
666	0.671	20.73980	32.34605	484	5	–		Samah Elsir
667	4.936	20.74030	32.34690	484	5	–		Dinah Abdul Gaffar
668	2.782	20.74358	32.34583	491	4	–	Doubtful	Horst Uwe Keller
669	7.582	20.74315	32.34642	493	1	–		Rana Faroug Badry
670	1.966	20.74285	32.34660	491	4	–		Mohammed Mustaffa
671	11.853	20.74290	32.34535	489	–	–	Fully crusted	Abdel M. Osman
672	6.820	20.74303	32.34497	489	3	–		Mark Hammergren
673	4.928	20.74287	32.34512	488	5	–		Rana Faroug Badry
674	1.885	20.74300	32.34472	488	3	–		Mark Hammergren
675	9.792	20.74145	32.34350	486	6	–		Eisam
676	17.509	20.73970	32.34305	485	5	–		Mohammed Salah
677	14.218	20.73915	32.34312	486	–	–		Alfad H. Al Rasoul
677A	–	20.73915	32.34312	486	–	–		–
678	4.651	20.73850	32.34305	483	3	–		Samah Elsir
679	5.540	20.73843	32.34275	484	–	–		Akram Moubarrack
680	3.076	20.73862	32.34212	483	–	–	Fully crusted	Akram Abdrachman
681	1.635	20.73670	32.34272	480	7	–		Abdal Hmeed M.
682	3.584	20.73633	32.34208	480	–	–		Saadia Elsir Satiri
683	1.255	20.73843	32.34008	483	–	–	Fully crusted	El Shafir
684	4.505	20.73915	32.34065	485	4	–		Muzimil Awad
685	1.157	20.73887	32.34107	485	3	–		Ekram
686	2.296	20.73857	32.34208	483	4	–		Abdalhy Muhammed
687	2.538	20.73823	32.33240	482	8	–		Heisam Abdelgaidir
688	9.159	20.73832	32.33185	483	1	–		Maisin
689	4.612	20.73802	32.33112	482	1	–		Petr Scheirich
690	7.864	20.73840	32.33098	482	6	–		Huda Yahia
691	2.908	20.73813	32.33062	481	3	–		Saadia Elsir Satiri
692	1.434	20.73870	32.33048	481	3	–		Moad Ibrahim
693	5.161	20.74195	32.33043	483	–	–	Fully crusted	Tamir Abel Alarir
694	37.106	20.74183	32.33103	482	4	–	Oriented? Big?	Adam Daoud Omer
695	7.793	20.74185	32.33105	482	1	–		Adam Daoud Omer
696	2.238	20.74202	32.33015	482	4	–		Amir Sousou
697	4.769	20.74205	32.33012	482	–	–		Carl Johannink
698	4.826	20.74208	32.33017	482	3	–		Tamir Abel Alarir
699	4.996	20.73948	32.33040	480	–	–	Fully crusted	Samah Elsir
700	3.415	20.73912	32.33053	481	3	–		Muzimil Awad
701	25.009	20.73940	32.32878	480	4	–	Big for area?	Moeid Haidar
702	9.152	20.73943	32.32875	480	4	–		Mohammed Salah
703	16.333	20.73865	32.32773	481	3	–		Nada M. Alameen
704	7.736	20.74023	32.32263	483	4	–		Amy Morrow
705	10.453	20.74142	32.32227	483	4	–		Mahmoud M. Ahmed
706	1.466	20.74112	32.32120	484	–	–		Wail Achmed
707	0.606	20.74108	32.32122	484	4	–		Bader Aldeen Musa
708	5.079	20.74100	32.32125	483	1	–		M. Ali Yousif
708A	–	20.74100	32.32125	483	–	–		–
709	1.594	20.74098	32.32117	484	–	–		Wail Achmed
710	2.569	20.74065	32.32098	484	5	–		Saadia Elsir Satiri
711	0.665	20.74067	32.32098	484	4	–		Saadia Elsir Satiri
712	1.878	20.74088	32.31513	482	4	–		Wail Achmed
713	14.546	20.73963	32.31505	482	–	–	Fully crusted	Mazin
714	–	20.76612	32.27502	495	–	–		Not known
715	2.602	20.75722	32.26977	492	–	–	Fully crusted	Esam O. Awdullah

Table 3. *Continued.* Almahata Sitta meteorite finds from 2009 expeditions.

UOK #	Mass (g)	Latitude (°) WGS84	Longitude (°) WGS84	Elev. (m)	Class	Type	Notes	Finder
December 11, 2009[d]								
2000	6.173	20.73628	32.36190	–	1	–		Alfahtih H. Al Rasoul
2001	0.379	20.73630	32.36217	482	–	–		Mohamed Demin
2002	4.887	20.73693	32.36188	–	3	–		Ismail Salih Araki
2003	3.523	20.73818	32.35928	–	3	–		Jacob Kuiper
2004	2.952	20.73815	32.35917	–	4	–		Adam Daoud Omer
2005	4.378	20.73918	32.35877	484	4	–		Mark Hammergren
2005a	19.819	–	–	–	4	–		Mark Hammergren
2006	0.796	20.73793	32.35742	483	1	–		Sana Yahia
2007	5.480	20.73812	32.35692	485	4	–		Adam Daoud Omer
2008	0.550	20.73885	32.35588	485	4	–		Tahani Shatir
2009	17.065	20.73900	32.35580	483	3	–		Loay A. Ibrahim
2010	14.815	20.74183	32.35505	484	4	–		Horst Uwe Keller
2011	4.843	20.74185	32.35507	483	–	–	Fully crusted	Amel S. El Deen Ali
2012	8.699	20.74228	32.35502	–	5	–		Horst Uwe Keller
2013	7.519	20.74237	32.35487	–	3	–		Horst Uwe Keller
2014	1.277	20.73672	32.35197	489	1	–		Omima Osman
2015	3.077	20.73715	32.35163	491	3	–		Petr Scheirich
2015a	3.159	–	–	–	–	–	Doubtful	Petr Scheirich
2015b	2.513	–	–	–	3	–		Petr Scheirich
2016	6.755	20.73715	32.35160	491	4	–		Tomas Kohout
2017	3.364	20.73710	32.35118	490	1	–		Omima Osman
2018	0.455	20.73747	32.35085	490	6	–		Bader Aldeen Musa
2019	1.064	20.73808	32.34728	487	5	–		Muhanad M. Shaib
2020	0.948	20.73803	32.34730	487	–	–	Fully crusted	Not known
2021	2.777	20.73762	32.34710	488	4	–		Muzimil Awad
2021a	4.419	–	–	–	–	–	Fully crusted	
2022	1.414	20.73753	32.34712	488	5	–		Alfadil Omer Alfad
2023	5.424	20.73758	32.34690	488	5	–		Mohammed Ali Yousif
2024	2.111	20.73765	32.34667	484	4	–		Ismail Salih Araki
2025	1.519	20.73810	32.34785	483	3	–		Muhamad M. Shaib
2026	2.902	20.73875	32.34423	478	–	–	Fully crusted	Mohammed Ali Yousif
2027	2.368	20.73882	32.34417	478	4	–		Bader Aldeen Musa
2028	37.351	20.73868	32.34780	484	3	–		Muhamad M. Shaib
2029	2.638	20.74162	32.34363	483	6	–		Rifgu Gidirdiri
2030	7.071	20.74185	32.34207	477	–	–		Frederic Vachier
2031	4.194	20.74182	32.34178	–	3	–		Frederic Vachier
2032	1.480	20.74008	32.34255	479	1	–		Dinah Abdul Gaffar
2033	2.328	20.73882	32.33923	478	–	–		Samah Elsir
2034	1.167	20.73860	32.33943	476	3	–		Mohammed Ibrahim
2035	1.019	20.73820	32.33812	–	3	–		Ahmed Isam
2036	6.055	20.73690	32.33793	–	1	–		Nada M. Alameen
2037	8.162	20.73768	32.33672	–	3	–		Abdal Hmeed M.
2038	4.792	20.74133	32.33455	475	–	–		Alla Adbarhaman
2039	8.830	20.74133	32.33453	475	3	–		Samah Sayed
2040	3.466	20.74188	32.32722	477	1	–		Ahmed Adoud
2041	8.402	20.74155	32.32767	–	7	–		Frederic Vachier
2042	8.987	20.74075	32.32900	–	3	–		Osama Ibrahim
2043	0.967	20.74072	32.32467	480	3	–		Frederic Vachier
2044	3.920	20.74178	32.32360	–	3	–		Alwaleed Ahmed
2045	4.513	20.74607	32.32210	–	3	–		Omer El-Tahir Harbi
2046	15.147	20.74607	32.32210	–	3	–		Omer El-Tahir Harbi
2047	6.675	20.74677	32.32202	–	3	–		Omer El-Tahir Harbi
2048	8.423	–	–	–	4	–		Mohammed Alameen

Table 3. *Continued.* Almahata Sitta meteorite finds from 2009 expeditions.

UOK #	Mass (g)	Latitude (°) WGS84	Longitude (°) WGS84	Elev. (m)	Class	Type	Notes	Finder
December 11, 2009[b]								
A85	–	20.73687	32.35183	487	–	–		Mohammed Elyas
A86	9.393	20.73695	32.35107	486	3	–		Mohammed Alameen
A87	21.256	20.73695	32.35107	486	7	–		Mohammed Alameen
A88	4.698	20.73698	32.35050	486	3	–		Mohammed Alameen
A89	7.854	20.73695	32.35038	486	–	–		M. Ali Yousif
A90	7.226	20.73702	32.35032	486	5	–		Mohammed Alameen
A91	2.253	20.73702	32.35032	486	5	–		Mohammed Alameen
A92	0.459	20.73702	32.35033	486	3	–	Doubtful	Mohammed Alameen
A93	4.728	20.73672	32.35055	486	5	–		Mohammed Alameen
A95	3.342	20.73680	32.34973	487	7	–		Mohammed Alameen
A96	1.102	20.73702	32.34982	487	1	–		Mohammed Alameen
A97	3.053	20.73703	32.34986	487	3	–		Mohammed Alameen
A98	1.693	20.73725	32.34986	487	4	–		Mohammed Alameen
A99	8.599	20.73758	32.34953	487	1	–		Jehad Osman
A100	11.356	20.73783	32.35062	488	6	Chond.		Mohammed Alameen
A101	4.148	20.73762	32.35083	487	7	–		Mohammed Alameen
A102	1.408	20.73765	32.35105	488	1	–		Mohammed Alameen
A103	0.832	20.73765	32.35105	487	1	–		Ekram
A104	–	20.73805	32.35052	487	5	–		Mohammed Alameen
A105	–	20.74132	32.34210	489	–	–		Mohammed Alameen
A106	11.814	20.74133	32.34167	489	–	–		Esam Omer Awdullah
A107	0.697	20.74058	32.34145	490	–	–		Mohammed Alameen
A108	–	20.74025	32.34089	490	–	–		Mohammed Alameen
A109	8.785	20.74078	32.33952	490	5	–		Suhaila Trofig
A110	0.660	20.73972	32.33870	490	7	–		Mohammed Alameen
A111	0.624	20.73993	32.33783	489	–	–	Doubtful	Mohammed Alameen
A112	1.900	20.73955	32.33753	490	7	–		Mohammed Alameen
A113	3.251	20.73955	32.33753	490	–	–		Omima Osman
A114	–	20.73978	32.33727	490	–	–		Omer El-Tahir Harbi
A115	6.599	20.73978	32.33725	490	–	–	Mass could be 114	Osama Murkaz
December 11, 2009, evening[a]								
1104	1.073	20.75430	32.26656	494	–	Ureilite	1 g survey	Stefan Loehle
1105	0.432	20.75343	32.26652	494	–	?	1 g survey	Lucy McFadden
1106	0.289	20.75337	32.26579	495	–	?	1 g survey	–
1107	1.815	20.75327	32.26543	495	–	?	1 g survey	–
1109	1.821	20.75304	32.26494	495	–	Ureilite	1 g survey	–
1110	6.877	20.75282	32.26445	495	–	Ureilite	1 g survey	–
1110a	0.734	20.75282	32.26445	495	–	Ureilite	1 g survey	–
1111	0.461	20.75248	32.26472	495	–	?	1 g survey	–
1112	2.375	20.75183	32.26515	495	–	Ureilite	1 g survey	Frederic Vachier
1113	3.737	20.75118	32.26558	494	–	Ureilite	1 g survey	Ibrahim
1114	0.381	20.75113	32.26553	495	–	Ureilite	1 g survey	–
1115	1.371	20.75157	32.26358	493	–	Ureilite	1 g survey	–
1116	1.787	20.75058	32.26493	495	–	Ureilite	1 g survey	Alfahtih H. Alrasoul
1118	0.917	20.74692	32.26222	490	–	Ureilite	1 g survey	Mohammed
1119	0.820	20.75113	32.26522	495	–	?	1 g survey	–
1120	1.107	20.74698	32.26228	489	–	?	1 g survey	–
December 11, 2009, evening[c]								
716	0.890	20.75375	32.26895	491	–	?	1 g survey	Muzimil Awad
717	1.052	20.75280	32.26860	491	–	Ureilite	1 g survey	Muzimil Awad
720	0.359	20.74978	32.26790	491	–	?	1 g survey	Beder Eldien
721	0.784	20.74965	32.26828	491	–	?	1 g survey	Muzimil Awad
722	0.993	20.74928	32.26830	490	–	Ureilite	1 g survey	Muzimil Awad
723	2.513	20.74840	32.26837	488	–	Ureilite	1 g survey	Assam Omer

Table 3. *Continued*. Almahata Sitta meteorite finds from 2009 expeditions.

UOK #	Mass (g)	Latitude (°) WGS84	Longitude (°) WGS84	Elev. (m)	Class	Type	Notes	Finder
724	2.586	20.74838	32.26822	489	–	?	1 g survey	Ahmed Isam
725	0.295	20.74923	32.26828	490	–	?	1 g survey	Muzimil Awad
726	0.393	20.74793	32.26847	489	–	Ureilite	1 g survey	Muzimil Awad
727	0.300	20.74745	32.26842	487	–	Ureilite	1 g survey	Aimad Aldeen
December 12, 2009[a]								
1213	0.769	20.75825	32.23454	508	–	Ureilite	1 g survey	–
1214	0.870	20.75835	32.23452	507	–	Ureilite	1 g survey	–
1215	0.994	20.75917	32.23492	507	–	?	1 g survey	–
1216	0.700	20.75938	32.23503	505	–	Ureilite	1 g survey	–
1217	2.390	20.75948	32.23508	505	–	Ureilite	1 g survey	–
1219	1.877	20.76348	32.23757	508	–	Ureilite	1 g survey	–
1220	1.571	20.76452	32.23820	508	–	Ureilite	1 g survey	–
1221	2.171	20.76312	32.23778	509	–	Ureilite	1 g survey	Frederic Vachier

[a]Collected by P. Jenniskens.
[b]Collected by M. Alameen.
[c]Collected by M. H. Shaddad.
[d]Collected by J. Herrin.

Table 4. Observed meteorite distributions cross-track of 2008 TC_3.[a]

Mass[b] (g)	Latitude[b] (°)	Longitude[b] (°)	Altitude[b] (km)	ΔLatitude (km)	SE (km)	Spread (1σ)[c] (km)	*N*
1.39	20.753	32.265	0.495	−1.819	±0.056	0.324	34
5.55	20.733	32.366	0.480	−1.791	±0.053	0.556	110
96.2[d]	20.710	32.508	0.467	−1.157	±0.246	1.348	30

[a]Relative to JPL#15 track (Table 1).
[b]Median values.
[c]Standard deviation of ΔLatitude.
[d]For masses >20 g.

which was found south of the main concentration of finds, and another meteorite found nearby, which was located only 2 m from a line of footsteps in the sand. Because of that, we adopt a detection efficiency of 90%. The combined mass recovered from the cross-track surveyed area amounts to a mass density at the surface per unit of distance along the track of 1.14 kg km^{-1} (which included masses for which the geographic coordinates were not recorded). There is no clear trend of mass density with position along the track, the density changing in 1 km intervals from 0.99 to 0.96, to 0.60 to 1.07 kg km^{-1}, from west to east, respectively, for the masses with known coordinates. After correction for collection efficiency, the average mass density along this part of the asteroid path is 1.3 ± 0.1 kg km^{-1}.

A second survey was conducted on a sandy plane near Marble Mountain at the 10 g point (Fig. 11). A 1 km wide line was started 2 km north of the asteroid path, and re-formed after passing Marble Mountain, then marched on until it was scattered by a large number of finds combined with a slow collection process. The search was restarted the next day from *asteroid track*, then continued on until 4 km south of the asteroid path (Fig. 11). Toward the end, the line had dispersed and veered off toward the west at the flank. Here, the landscape showed varying terrain, including rock outcrops and very course gravel at places (Fig. 6). The collection efficiency is hard to estimate and varies from place to place. Observers tended to clump in groups over time, especially after passing hills in the landscape. We revisited the site during the fourth search, starting on the sandy plain and walked along-track toward the west. A significant number of new fragments (but not so much mass) were recovered in the area (Fig. 1, crosses). In an area where 847 g of meteorites (26 individuals) had been found before, another 140 g was found (28 individuals). Even then, the area was probably not fully depleted. From this, we estimate a collection efficiency of about 75% for the first survey alone when 1.04 kg km^{-1} of mass was recovered, for a total mass density of 1.4 ± 0.2 kg km^{-1} per unit of distance along this part of the asteroid path.

During the fourth survey, a third cross-track traverse was added near the location where 1 g meteorites fell (Fig. 12). The first scan was conducted in very rocky terrain late in the afternoon. All told, 39 searchers participated, spread over 700 m, but each

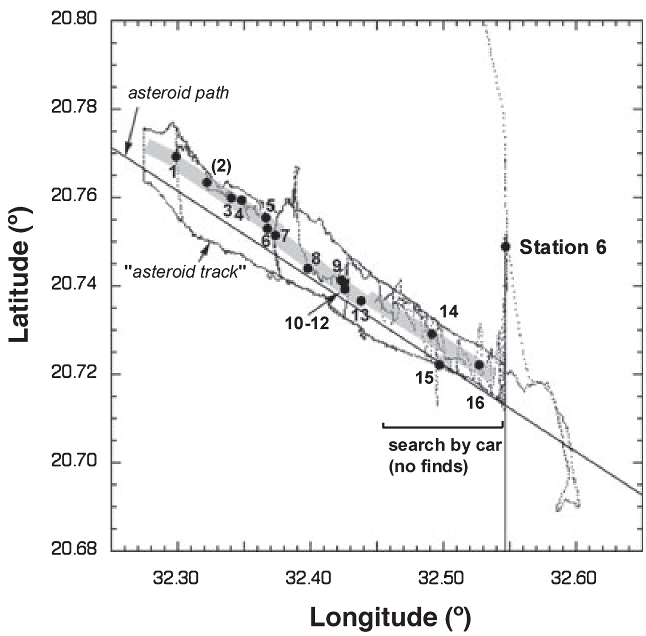

Fig. 7. Location of the first finds. A 0.5 km wide line searched the gray area. The position of the projected asteroid path is shown by a solid line. The road created to support the search effort is called "asteroid track."

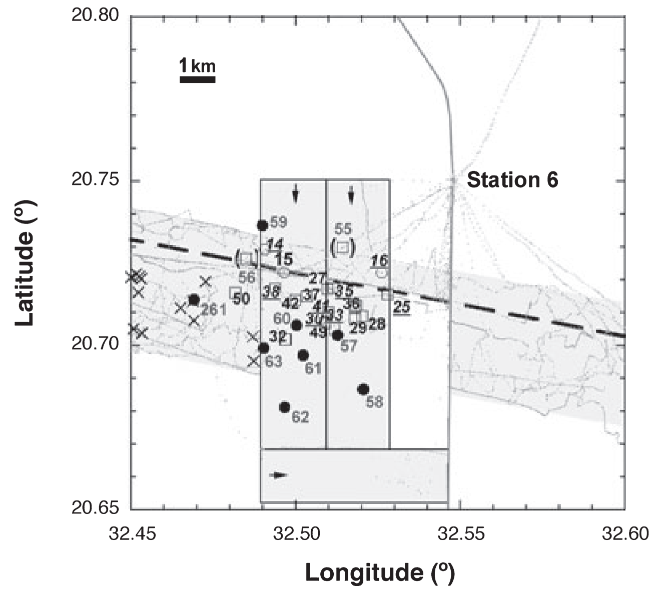

Fig. 8. The cross-track search area for large (~100 g) fragments. Gray areas were searched. Finds are marked as open circles (first search), open squares (second), closed circles (third), and crosses (fourth search). Walking directions are indicated by arrows. Black numbers refer to the finds listed in Table 2, with underlined italic numbers pointing to the location of nonureilite meteorites in the strewn field.

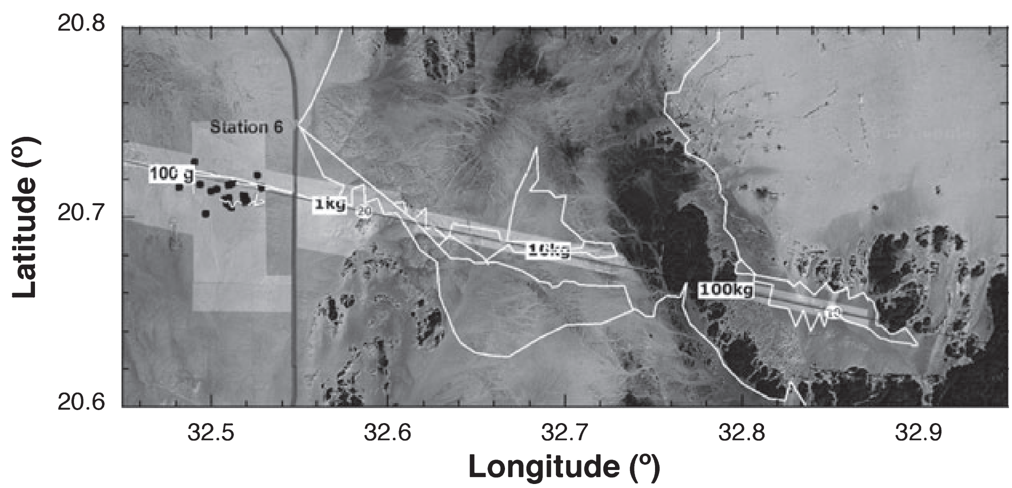

Fig. 9. Overview of the search for larger (1–100 kg) fragments. None were found during searches by foot in the light areas. Light solid lines are the GPS track record that trace the movements by car of M. H. S. during the second search.

effectively covered only an area about 5 m wide, together effectively covering less than a 200 m wide strip. The search was started 500 m north of the asteroid path and continued until about 3 km south of the path. Toward the end, the terrain became more sandy, but the low sun elevation made searching difficult. Twenty-six meteorites with a total mass of 36 g (mean mass of 1.39 g) were found, for a mass density of only >0.18 kg km^{-1}. This is only a lower limit, because we suspect bias from terrain conditions given that the meteorites were very inhomogeneously distributed (Fig. 12). The search was repeated on the fourth day, on an ideal sandy area with light-colored gravel just beyond the ridge (Fig. 12). In total, 11 individuals participated in this search and were put at arm's length, over a distance of 23 ± 2 m (Fig. 13). A region of about 2.5 km south of the asteroid path until 0.5 km north of the path was searched. The detection efficiency was high, certainly higher than 30%. seven meteorites were found with a mean mass of 1.31 g and a total

Fig. 10. The largest surviving fragment of asteroid 2008 TC_3 in situ. Sample #62 (location shown in Fig. 8) was found by Peter Jenniskens (left) and driver Abrahahim Hamdan during the third search while catching up on the line. A sandstorm the day before left a trail of large sand grains in the wake of the meteorite.

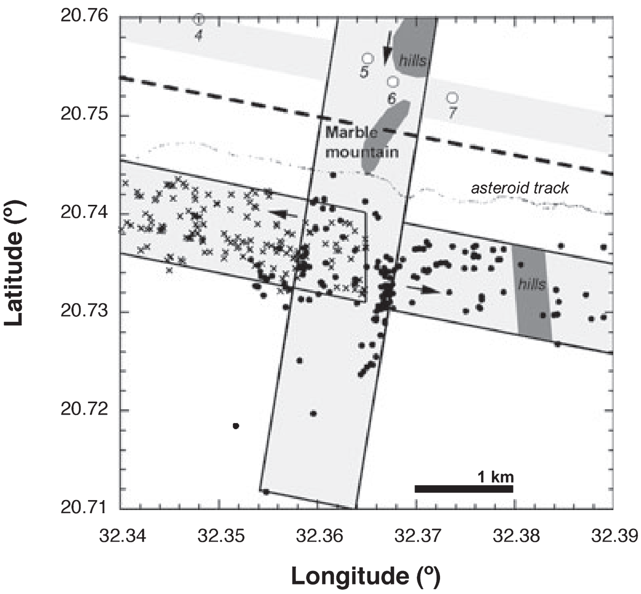

Fig. 11. The cross-track survey of the 10 g point (black dots). The line was re-formed after passing Marble Mountain, but spread out and veered off to the west at the flank later in the day. Also shown are two along-track search areas from the third (right) and fourth (left) surveys. Symbols as in Fig. 8.

mass of 9.17 g. The largest sample was 2.39 g, the smallest 0.70 g. This amounts to a fallen mass of between 0.40 and 1.2 kg km^{-1}. This uncertainty is due to the fact that it is not clear if the southern extend of the strewn field was searched or not, in the direction of which small masses would have drifted.

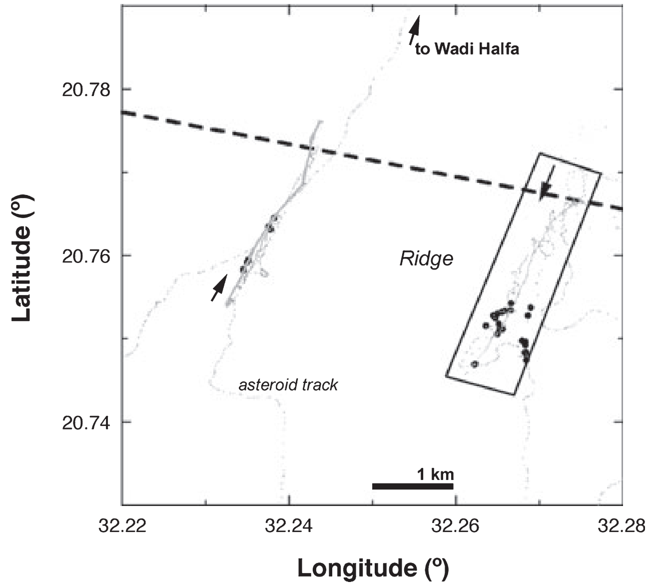

Fig. 12. The 1 g survey consisted of two scans in rocky (right) and sandy (left) terrain, separated by a steep ridge. Dots mark the finds (from the fourth search).

Fig. 13. Searching for 1 g pieces. Two recovered samples are shown. One is a ureilite (right), the other possibly a chondrite (left). From left to right: Jason Herrin, Francois Colas, Badr Eldeen Musa, Mohamed Ali Yousif, Ibrahim Farouq Ibrahim, Mohammed Alameen, Lucy McFadden, Omima Osman, Frederic Vachier, Muzamil Awad, and Osama Ibrahim Mohamed.

We conclude that the mass density was approximately constant at 1.3 ± 0.1 kg km^{-1} over a length of 30 km, with by an abrupt termination near the position of the main mass and possibly a drop off closer to the explosion point for masses <1 g. This amounts to a total fallen mass of 39 ± 6 kg. Of this fallen mass, we recovered 10.7 kg so far.

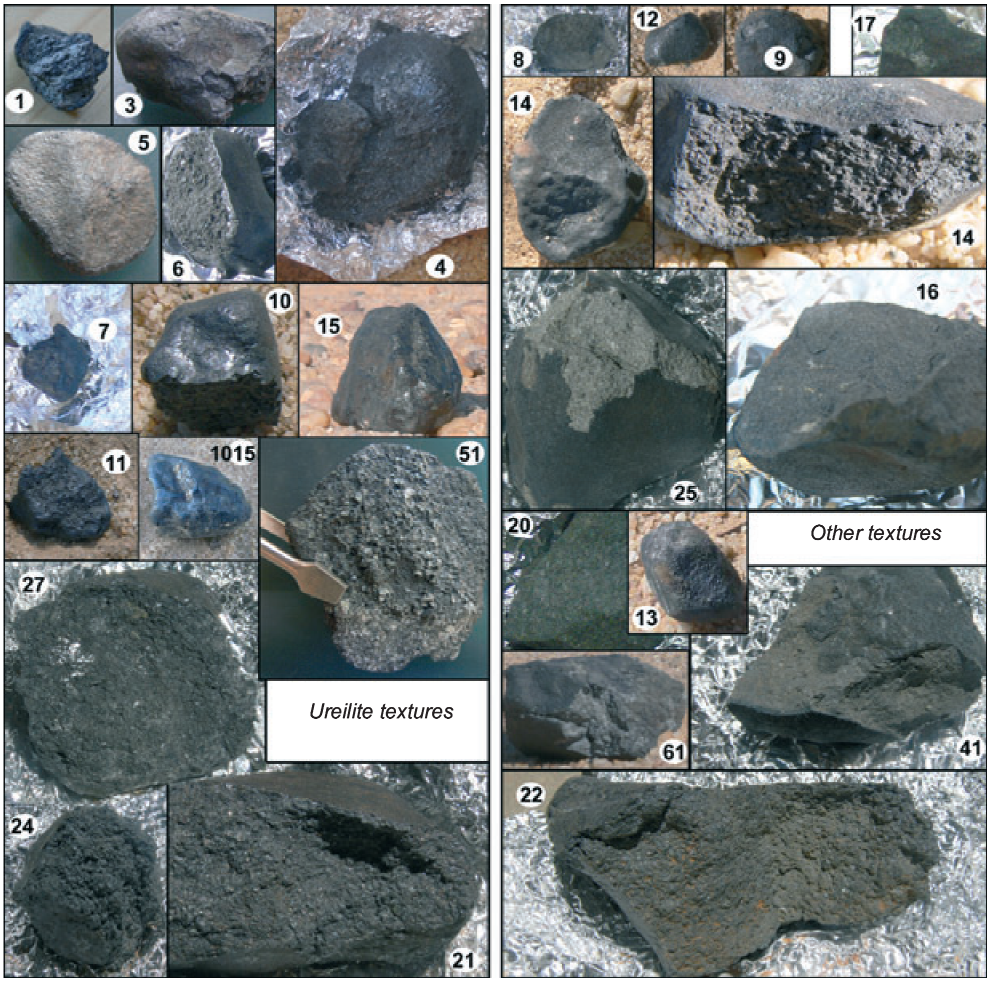

Fig. 14. Examples of Almahata Sitta meteorites with ureilite textures (left) and other textures (right). The image scale for each meteorite varies from 2.5 cm (#7) to 8 cm (#27) across and sample numbers refer to Tables 2 and 3. Ureilite textures are identified from those meteorites typed as ureilites. Sample #5 shows the back side of a fully crusted oriented meteorite. Other textures include those of an H5 chondrite (sample #25), an EH6 chondrite (#16), and an EL6 chondrite (#41).

THE METEORITE PROPERTIES

From the first search, it became clear that the strewn field contained fresh-looking meteorites with a range of textures and albedos. They all had a dark fusion crust, with some showing no signs of weathering, others only had small rusty spots. The first sample recovered, the 4.4 g sample #1 (Fig. 14, top left), had such rusty spots and was later found to be an anomalous polymict ureilite with a unique layered texture (Jenniskens et al. 2009; Friedrich et al. 2010). The porous morphology is best explained by originating from loosely packed fine-grained fragments. There is no doubt that this meteorite was part of asteroid 2008 TC_3, given the rarity of freshly fallen ureilites.

By contrast, the large 222 g sample #25 (Fig. 14) was slightly weathered on one side, but otherwise fresh looking. Microprobe analysis of FeOx determined that the meteorite had fallen less than a few months prior (Zolensky et al. 2010). It was determined to be an H5 chondrite, but with the same unusual PAH (polycyclic aromatic hydrocarbons) signature as other fragments of asteroid 2008 TC_3 (Sabbah et al. 2010). Sample #25 was found among other ureilites of similar size (Fig. 8).

Indeed, even among the 1 g samples, we found some samples that were distinctly different in texture (Fig. 13). All small samples from the 1 g vertical scans were measured for magnetic susceptibility (Kohout et al. 2010) and 13 of 34 (23% in mass) were found to have a value higher than that of the ureilites, values that are more typical for high-iron ordinary or enstatite chondrites (or even CH and CB type carbonaceous chondrites).

In a first attempt to distinguish among different textures, Table 2 refers to seven different meteorite textures as shown by class archetypes meteorites #27

(1—scruffy, black), #7 (2—porous, layered), #22 (3—gray, course, bubbly), #24 (4—gray, course, large grains), #16 (5—gray, fine grained), #25 (6—light colored, chondrules), and #41 (7—light gray, fine grained, like concrete). Meteorites #27, #7, and #22 were subsequently classified as ureilites, whereas meteorite #16 was classified as an EH6 chondrite, #25 as an H5 chondrite, and #41 as an EL6 chondrite. However, keep in mind that not all meteorites of the same texture class need to belong to the same meteorite type. Sample A100, for example, a class 6, was identified as an L4 chondrite, not an H5 chondrite.

The Meteorite Density

The density of the meteorites recovered in the first two searches (samples 1–54) was measured using course orange-colored sand. The specific density (mass per volume) of the sand was measured 12 times (room temperature $T = 30$ °C) using a 100 mL volume glass with accuracy of ± 0.5 mL (1.591 ± 0.015 g mL^{-1}). Then, each meteorite was immersed in sand in a small container, measured to have a volume of $V = 87.90 \pm 0.91$ mL, or a larger container ($V = 269.5 \pm 3.3$ mL). The containers were shaken by hand until the sand grains had settled sufficiently for it to feel like a solid mass, but no more. The container was also measured filled with sand alone and the meteorite's mass was measured. The volume of the meteorite was derived from: V = ([mass meteorite + sand + container] − [mass meteorite + container])/[mass/volume sand]. Some meteorites were too big to fit in the container used and those were not measured.

Results are presented in Table 2 and Fig. 15. A wide range of values was obtained, ranging from $3.11 + 0.14/-0.07$ g cm^{-3} for ureilite sample #15 down to $1.77 + 1.08/-0.39$ g cm^{-3} for ureilite sample #1. Most larger ureilites scatter around the 2.8 g cm^{-3} value of sample #27, the largest sample of confirmed ureilite material. The smaller samples are strongly affected by uncertainties in the measured sand density, and consequently have a large measurement error. For example, if the sand density was only 1.568 g cm^{-3}, the measured density of sample #1 would increase to 3.55 g cm^{-3}. Our medium shake produced a sand density of 1.591 ± 0.013 g cm^{-3} (1σ error, from 10 measurements, removing two outlayers) the value adopted in the calculations. Well-shaken sand had a density of 1.563 ± 0.025 g cm^{-3}.

Britt and Consolmagno (2003) measured an average ureilite density of 3.05 ± 0.22 g cm^{-3}. Many of our samples fall below this range and at least two of those were found to be rich in pores (#1 and #7; Fig. 14). These are the anomalous polymict ureilites reported in Jenniskens et al. (2009). Three samples were examined by synchrotron X-ray microtomography at the GSECARS beamline 13-BM at the Advanced Photon Source of Argonne National Laboratory using techniques as described in Friedrich et al. (2008). The entire fragment of sample #1 was imaged (Fig. 16), and digital isolation of the meteorite, fusion crust included, yielded a density of 1.485 g cm^{-3}, in agreement with the much less accurate result from the sand measurements. Errors for our X-ray tomography digital isolation techniques are ≤6% (Friedrich et al. 2008 and references therein). By contrast, the more monomict-looking sample #4 (a small fragment) gave a density of approximately 3.09 g cm^{-3}, in good agreement with the mean value given by Britt and Consolmagno (2003), and the $2.55 + 0.61/-0.26$ g cm^{-3} value measured using sand (Table 2).

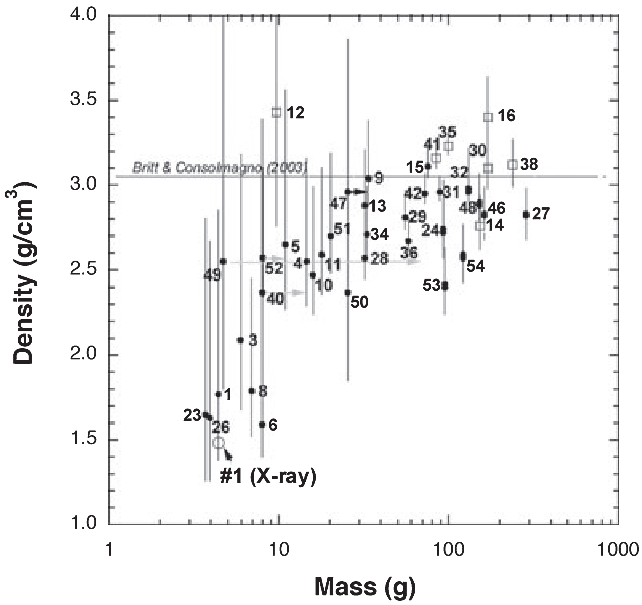

Fig. 15. The density of the meteorites as a function of mass. The mean density of other ureilites measured by Britt and Consolmagno (2003) is shown as a dashed line. Open squares are meteorites with anomalous texture, which include nonureilites. The open circle is the density measured for sample #1 by X-ray tomography. Sample numbers refer to Table 2.

The lighter-colored finer-grained meteorites that are unlike sample #27 tend to have higher densities. At least some are not ureilites. Among the samples of the first survey, samples 14 and 16 were determined to have higher magnetic susceptibilities than the ureilites. Sample 16 was very fine grained and lighter of color (Fig. 14), and was subsequently determined to be an EH6 enstatite chondrite. Sample 14 had rounded grains at the surface, presumably from chondrules (Fig. 14). This meteorite has not been classified yet. Among those

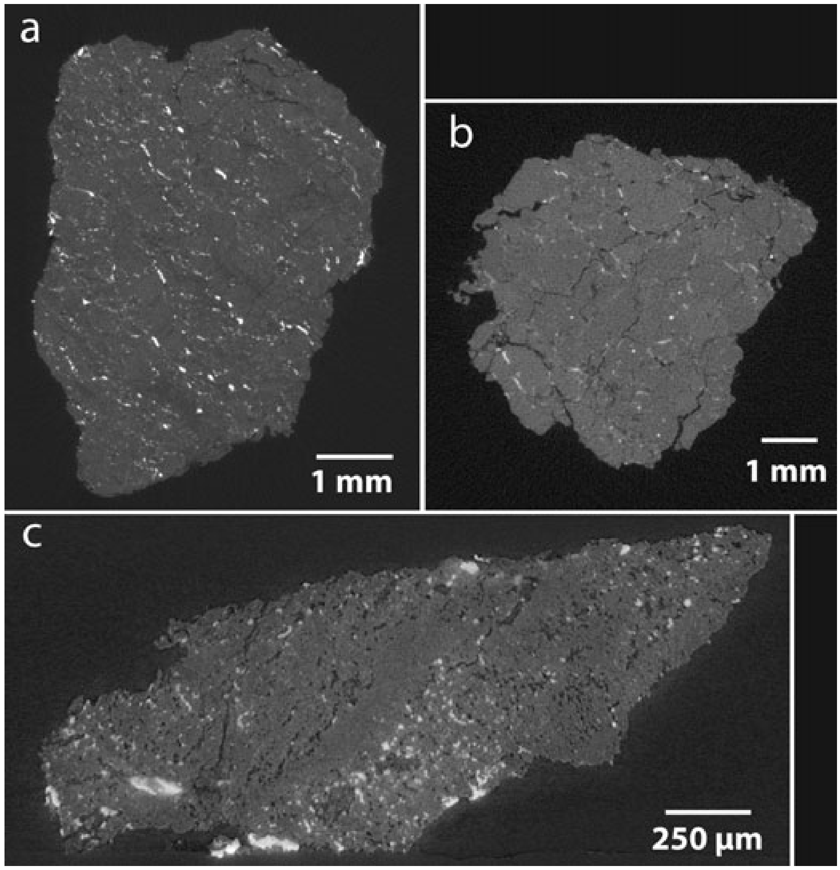

Fig. 16. Synchrotron X-ray microtomographic "slices" of three fragments of Almahata Sitta collected at various resolutions. a) Tomogram of fragment #1 collected at 13.5 μm per voxel (a voxel is a 3-D pixel). b) Tomogram of a subsample of fragment #4 collected at 15.9 μm per voxel. c) Tomogram of a small (~2 mm) chip of fragment #7 collected at 1.9 μm per voxel. Lighter grayscale areas are metal-rich, high-Z material. Dark areas are pores and air surrounding the sample. Intermediate grayscale regions are silicate material. Cracks and pores are easily discerned within the meteorite, demonstrating the porosity is primarily present as micropores and cracks within samples #1 and #7. Fragment #1 has a distinct foliation (also see Fig. 14), while fragment #4 does not possess the same foliated texture.

of the second search, most of samples 17–54 crumbled easily. Subsequent studies of the crumbs showed these to be ureilites (Rumble et al. 2010; Sandford et al. 2010). On the other hand, samples 25, 26, 30, 35, 38, and 41 had distinctly different textures from the others and did not shed material so easily. Sample 25 and 41 were classified as an H5 ordinary chondrite and an EL6 enstatite chondrite, respectively. These anomalous samples accounted for 32% of the recovered mass in the second search.

Because these are higher density materials, it is likely that their mass fraction over-represents that of the foreign clasts in asteroid 2008 TC_3.

There is no correlation of meteorite density with cross-track distance from the 2008 TC_3 path, except, perhaps, that the small low-density meteorites were found at the edge of the field, farthest from the path.

The mass dispersion at any given point along-track (Fig. 17) is significant, covering about 1 order of magnitude in mass at a given location. Among the larger masses, however, the smallest fragments are likely secondary fragments created during the fall, given that these were found close to larger fragments on the ground. Significant fragmentation also occurred in the air, after ablation had stopped. Most recovered meteorites (but typically not the many oriented meteorites) had broken surfaces without nearby fragments. This could have been the result from rapid tumbling, coupled with a low tensile strength. The same was observed for the fragile Tagish Lake meteorite which, too, had a high fraction of oriented meteorites (Brown et al. 2001).

There is no sign yet that the anomalous meteorites were found in specific areas in the strewn field, as expected if older strewn fields overlap the search area. The expected recovery of old meteorites is about 0.2–10 finds per km^2 (Gattacceca et al. 2009). With about 50 km^2 of area surveyed, this suggests that between 10

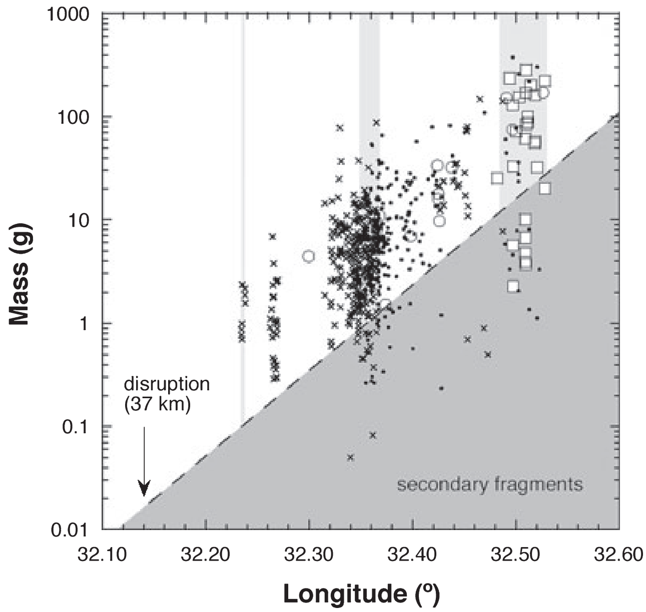

Fig. 17. The distribution of masses as a function of longitude of the find location. Symbols as in Fig. 8. The gray vertical bars mark where the cross-track surveys were conducted. The shaded region is marked as "secondary fragments," which are fragments created during impact, because they were found in pairs or near larger fragments.

and 500 foreign meteorites should be part of the collection. However, the searchers did not look for weathered (brown-looking) meteorites. Only black fresh-looking meteorites were targeted.

DISCUSSION

Almahata Sitta yielded a large number of small meteorites, instead of the more typical small number of relatively large fragments (e.g., Jenniskens et al. 1994; Borovička and Kalenda 2003; Brown et al. 2005). The high end height of the meteor made this a PE type IIIa/b type fireball, typical of fragile cometary material (Ceplecha et al. 1998). The asteroid was disrupted beginning at 46–42 km at a low tensile strength of 0.2–0.3 MPa, slightly less than the approximately 0.3 MPa required to break the parent body of the Tagish Lake meteorite fall, a PE type II/IIIa fireball (Brown et al. 2001), which penetrated down to 27 km (Hildebrand et al. 2006). We now know that if the object is large enough (on the order of meters in diameter in the case of 2008 TC_3), such that a significant number of fragments are deposited, then small fragments of relatively fragile materials such as contained in Almahata Sitta can be found in orchestrated searches. Interestingly, finding small pieces in a dense debris field may be easier than finding a single large mass in a large strewn field.

The Breakup Altitude

Fragmentation was most violent between 40 and 35 km, peaking in the flare around 37 km altitude (Jenniskens et al. 2009). It is possible that the recovered meteorites originated from ablation higher up in the atmosphere, given the early detection of the fireball at 65 km by U.S. government satellites. The significant along-track dispersion of masses (Fig. 17) provides a measure of the ablation altitude. Assuming that all fell as spheres, with no ablation or fragmentation, the range in longitude over which a given mass was detected provides a maximum range of ablation altitude. From Fig. 17, we find that the spread of a given mass is about 0.12° in longitude, if we assume that the smaller <10 g fragments found among the largest meteorites were created during the impact on the ground (indeed, they were typically found nearby larger meteorites). This would correspond to a range of 4.7 km in altitude along the trajectory of 2008 TC_3. Hence, much of the ablation occurred in a narrow range of altitude, most probably between 40 and 35 km. This suggests that much of the surviving fragments originated from the catastrophic disruption at around 37 km.

The Influence of Winds (Falling Sphere Model)

The location of the strewn field south of the calculated asteroid path remains an enigma and posed a significant problem in finding the first meteorites. The highest density of meteorites was almost 2.3 km south from the expected location in Fig. 1. Because the strewn field was only 1 km wide at its densest part (but with wide wings to the distribution), we could easily have found nothing in our first search had we started searching a mere km further north. At first sight, the winds did not seem to explain the systematic shift of the fragments, but we will now investigate this possibility further.

Table 5 (and Fig. 4) summarizes the prevailing winds between 65 km altitude and the ground (at about 490 m above WGS-84), derived from different sources. The UKMO wind model for October 7, 2008, at 12 h UTC and the European Centre for Medium-Range Weather Forecasts (ECMWF) model for October 7, 2008, at 0 UTC are in fair agreement, and both agree well with the available observations: the radiosonde observations at Aswan at 12 h UTC and the wind drift data derived from the Meteosat 8 and 9 observations of the dust cloud at the time of the event (Borovička and Charvát 2009).

Based on these wind data, one can adopt the known approach path of asteroid 2008 TC_3 (Table 1), assume a fragmentation point and from that the initial

Table 5. Vertical wind profile over fall area.

		UKMO			ECMWF		
Alt. (m)	Pressure (Pa)	W[b] (vertical) ($Pa\ s^{-1}$)	Horizontal speed ($m\ s^{-1}$)	Direction azimuth (°)	W (vertical) ($Pa\ s^{-1}$)	Horizontal speed ($m\ s^{-1}$)	Direction azimuth (°)
53	1000	56.8	4.8	56.8[a]	–	5.3	68
519	950	56.2	6.1	56.2	–	–	–
761	925	56.9	6.6	56.9	–	–	–
1007	900	57.1	6.7	57.1	–	–	–
1515	850	57.8	6.7	57.8	–	11.9	68
3178	700	58.4	6.5	58.4	–	7.8	45
4432	600	53.7	7.4	53.7	–	–	–
5863	500	105.6	8.4	105.6	–	8.6	90
7567	400	139.6	8.8	139.6	–	7.8	180
9651	300	200.0	7.8	200.0	–	5.3	203
10,903	250	208.2	8.8	208.2	–	–	–
12,373	200	218.6	5.0	218.6	–	6.1	203
14,167	150	242.5	1.8	242.5	–	–	–
16,545	100	197.3	2.7	197.3	–	5.3	180
18,599	70	19.6	3.4	19.6	–	–	–
20,619	50	130.9	6.2	130.9	–	–	–
23,801	30	132.7	4.7	132.7	–	–	–
26,415	20	83.9	5.9	83.9	–	–	–
28,304	15	76.9	8.5	76.9	–	–	–
31,033	10	81.0	10.7	81.0	–	–	–
33,443	7	111.3	12.9	111.3	–	–	–
35,736	5	111.9	9.0	111.9	–	–	–
39,305	3	1.7	13.7	1.7	–	–	–
42,266	2	347.8	8.9	−12.2	–	–	–
47,583	1	230.5	16.1	230.5	–	–	–
50,279	0.7	244.4	25.8	244.4	–	–	–
52,912	0.5	253.7	28.1	253.7	–	–	–
54,526	0.4	258.6	29.8	258.6	–	–	–
56,736	0.3	248.9	30.1	248.9	–	–	–
64,005	0.1	236.0	32.0	236.0	–	–	–

Note: Vertical wind profile over 50 km height location of asteroid 2008 TC_3 entry path on October 7 at 12 UT, based on the UK Meteorological Office (UKMO) model (Swinbank and O'Neill 1994) and the European Center for Medium-Range Weather Forecast (ECMWF) model on October 7 at 00:00 UT.
[a]Blows from ENE to WSW.
[b]Pressure vertical velocity.

velocity vector, and drop a sphere to Earth to calculate the displacement along track and tangential to the track. Initially, we adopted a breakup point at 37.0 km altitude with no instantaneous deceleration, hence a forward speed of 11.71 km s^{-1} and a downward speed of 4.07 km s^{-1}. A density of 2.8 g cm^{-3} was assumed. We calculated that the meteorites drift north from shortly after the point of breakup to about 5 km altitude. Below 5 km, the wind direction changed (Fig. 4), causing the fragments to drift back south. Because the meteorites fall most slowly at these altitudes, the wind has more time to change their trajectory. As a result the meteorites drift almost all the way back and end up falling just north of the calculated track, small masses more so than larger masses. We calculated that the along-track dispersion of masses is close to that measured. Masses below a few hundred grams would have lost all of their forward cosmic velocity at the time of impact (V_{long} impact). It is not clear why all recovered masses would fall in this category.

A more sophisticated approach was taken using the University of Western Ontario dark flight software package (Edwards et al. 2004; Brown et al. 2010). This calculation started from the top of the atmosphere, using an initial mass of 80 tonnes, and the known entry conditions (velocity, entry angle, etc.). It was assumed that ablation proceeded according to a type IIIa body. Next, this ablation was followed down to 37 km altitude, at which point the asteroid underwent a catastrophic disruption. Pieces of various sizes were followed immediately after this detonation down to an altitude until their velocity reached 4 km s^{-1}. At this point, it was assumed that ablation ceased and dark

Table 6. Calculated wind drift of falling meteorites (UWO model).[a]

Mass (g)	Fall time (s)	ΔLong. (km)	ΔLat. (m)	V_{impact} (m s^{-1})	Spread tangential (2σ, km)	Spread in-path (2σ, km)
1.4	722.6	+11.800	+500	22.203	1.59	4.93
4.1	600.8	+15.711	+387	26.228	1.93	5.97
24	446.6	+23.078	+227	34.566	2.31	7.48
100	345.4	+30.449	+170	44.117	2.67	8.54
270	295.9	+35.245	+169	51.142	2.85	9.10
730	249.2	+40.736	+190	60.261	2.99	9.86
1400	222.2	+44.478	+209	67.230	3.13	10.25
3000	195.7	+48.678	+219	75.884	3.14	10.71
5000	178.9	+51.682	+215	82.668	3.21	10.91
11,500	155.4	+56.451	+192	94.543	3.21	11.00

[a]Adopted ground elevation = 450 m (WGS84). The latitude difference is with respect to the latitude of the asteroid path (Table 1) at the longitude of the impact location. The longitude difference is with respect to the 37 km longitude of 32.14003°. In the last column, are the approximate 2 sigma ellipse minor/major axes of possible fall areas for these sizes (centered on nominal positions). This ellipse assumes a horizontal uncertainty in the initial release point of ±100 m perpendicular and ±700 m along track, with a mean tangential or lateral velocity of 200 m s^{-1} at the time of release.

flight began. From this point, at each size, the pieces were followed to the ground, presuming each was a sphere with density of 2.3 g cm^{-3}.

Results are presented in Table 6. Figure 18 shows the dispersion of fragments on the ground, relative to the asteroid path, the explosion point, and the locations where ablation ceased for the various masses in ascending order of mass (i.e., the largest mass penetrated deepest). The model correctly calculated that for meteoroids producing masses of 270 g on the ground, the ablation ceased at 32 km altitude, in agreement with observations. The largest piece we followed (11 kg) ablated down to 27 km altitude, but no such large fragment was later recovered.

For the nominal wind model, the meteorites do not fall far enough south. The mean of impact locations are just north of the calculated approach path (Fig. 18), leaving a significant discrepancy with observations. For 1.4 g pieces, we measured a latitude displacement of −1.82 ± 0.06 km (Table 4), and calculated a displacement of +0.50 km (Table 6). For 5 g meteorites, we measured −1.79 ± 0.05 km, and calculated +0.39 km. For 100 g meteorites, we measured −1.16 ± 0.25 km and calculated +0.17 km. The discrepancy (observed−calculated) is −1.33 ± 0.25 km for the largest masses, and about −2.3 ± 0.1 km for the smaller masses.

From the systematic shift, nearly independent of mass between 1 and 100 g, we suspect that this discrepancy is on account of the uncertainties in the prevailing winds. Changing the southerly winds below 8 km to 15 m s^{-1} results in mean displacements of −4.162, −2.661, and −2.045 km s^{-1}, respectively. A southerly wind speed of about 11 m s^{-1} (darker gray bar in Fig. 4) is needed to explain the observed location of the meteorites (Fig. 4). Hence, a stronger southerly tropojet is more than enough to move the meteorites to the measured location.

However, another possible explanation for the observed shift is that the calculated approach path of the asteroid is in error, which deserves further study. Some other possible explanations, such as directional ejection of fragments during the explosion, would cause a rotation in the orientation of the strewn field, which is not observed.

In our model, we adopted an isotropic lateral velocity of 100 m s^{-1}, with a spread of σ = 40 m s^{-1} (full width at half maximum [FWHM] ~ 94 m s^{-1}). This corresponds to a lateral velocity dispersion centered on 0 m s^{-1} (FWHM = 120 m s^{-1}). We also calculated the dispersion for double the lateral velocity and spread, or FWHM = 240 m s^{-1} (Fig. 18). A total of 1000 fall trajectories were calculated with slightly different initial ejection conditions, from which the cross-track spread on the ground is calculated for each mass. That spread is very small, only of the order of 1–2 km. Of course, lift from various shapes of each fragment (especially in the case of oriented meteorites), different release altitudes for end of ablation, and higher lateral velocities will all add to the cross-track spread.

Even large masses were predicted to fall a similar amount displaced from the asteroid's trajectory as the smaller masses (Table 6). The observed 1σ dispersions of 0.32, 0.56, and 1.35 km for 1.4, 5.6, and 96.2 g masses, compare to calculated dispersions of 0.80, 0.97, and 1.34 km for a tangential velocity of 200 m s^{-1}, a factor of 2.5, 1.7, and 1.0 higher. It is possible that the full dispersion of the 1 g meteorites was not fully measured, given the southern extend of the survey. However, the dispersion of the 10 and 100 g samples is well measured. This implies a best fit lateral velocity dispersion of about FWHM = 140 ± 40 m s^{-1} (or slightly less if the observed dispersion is increased by lift and nonspherical fragments).

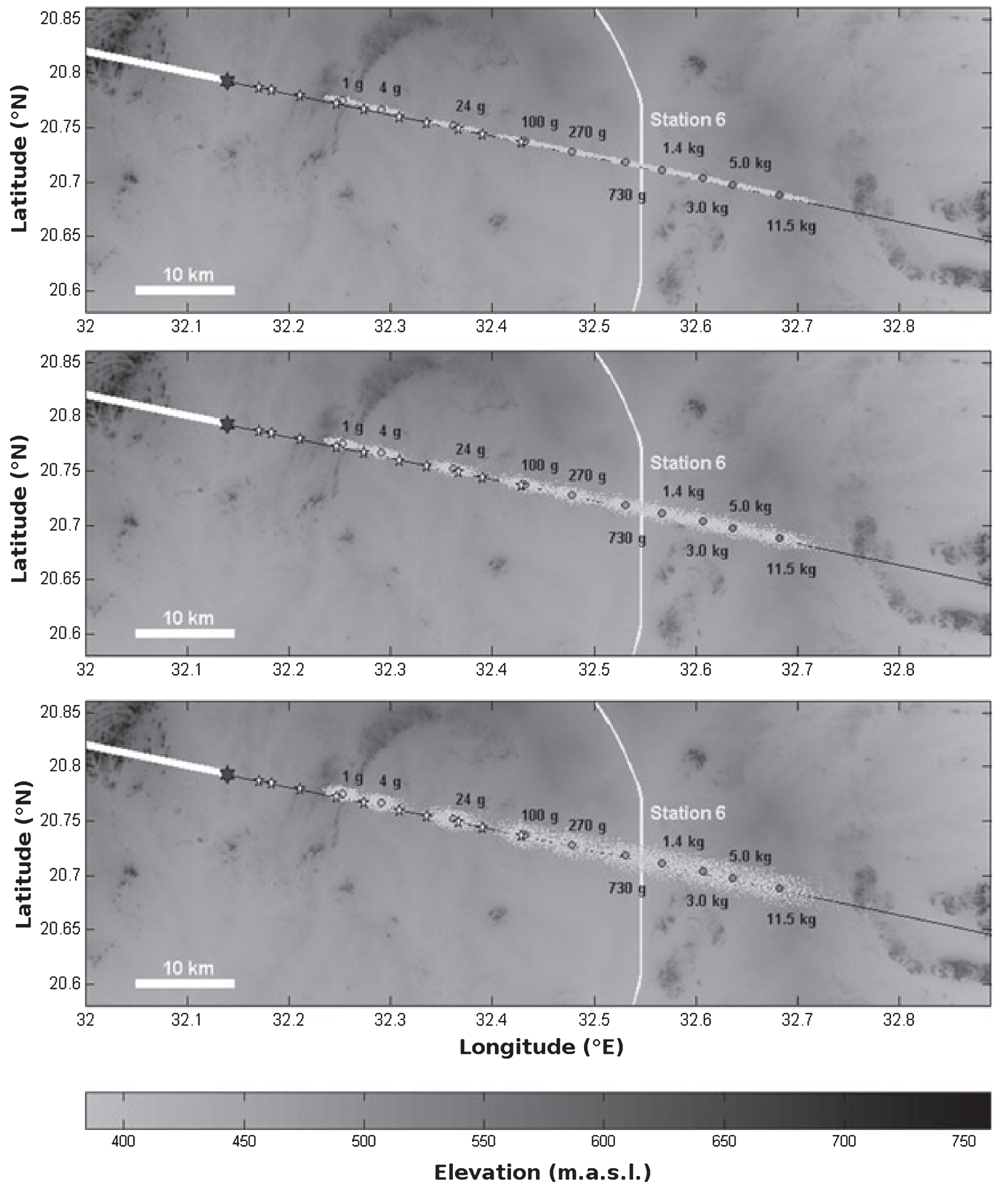

Fig. 18. The calculated strewn field based on release of meteorites at 37 km altitude, followed by ablation and deceleration until the speed had declined to 4 km s^{-1} (shown by a star symbol), then dark flight trajectory after that (with mean fall locations shown as open circles). The top graph shows the error ellipse due to uncertainty in the position of the release point at 37 km altitude, taken to be ± 100 m perpendicular and ± 700 m along track. Second graph shows the dispersion if, in addition to uncertainty in the release point, there is a finite isotropic ejection speed of 100 m s^{-1}, with a dispersion of $\sigma = \pm 40$ m s^{-1}. Bottom graph is the same for release at double this speed (200 m s^{-1}).

Borovička and Kalenda (2003) give a histogram of lateral velocities for 27 fragments from the Morávka meteorite fall. The distribution is approximately Gaussian in shape with a peak at -1 m s^{-1}, a FWHM of about 100 m s^{-1}, and a maximum measured value of 310 m s^{-1}. We conclude that the cross-track velocity imparted on fragments during the disruption of 2008 TC_3 was not unlike that of the more typical Morávka meteorite fall. Hence, the catastrophic disruption of 2008 TC_3 did not impart significantly more kinetic energy on the fragments than did the breakup of Morávka.

CONCLUSIONS

Over 600 samples of asteroid 2008 TC_3 have been recovered, with a total mass of 10.7 kg. This is estimated to be only approximately 27% of the total fallen mass of 39 $\pm$ 6 kg. The fragments fell at a near-constant density of 1.3 kg km^{-1} per unit distance along the ground-projected trajectory of the asteroid, between masses of 1 and 400 g. The largest recovered mass is 379 g.

About 20–30% of the recovered mass consists of freshly looking meteorites other than ureilites. This percentage is similar among small (1 g) and large (100 g) fragments. They have sizes similar to other recovered ureilites in the strewn field and were therefore part of asteroid 2008 TC_3, being released at the same time during fragmentation. Because only fresh-looking meteorites were targeted, very few are expected to have originated from prior falls in the area.

Most material appears to have dispersed when the asteroid was in the narrow 40–35 km altitude range, where it occurred its most significant disruptions. These disruptions did not impart more kinetic energy on the fragments than typical for lower altitude meteorite falls such as Morávka. Many meteorites emerged from these disruptions rapidly tumbling and continued to fragment even when they had been slowed down to below 4 km s^{-1} and ablation had ceased. They landed 0.4–1.0 km further south than expected, possibly because the prevailing winds below 8 km were different from those derived from the two wind models used here.

The Almahata Sitta strewn field is unique in that it contains many different meteorites, some types of which may not yet have been recovered. Only the pattern of fragments of a given material in the field can potentially reveal information about their relative position in the asteroid, as well as the presence of prior falls in the area that may have introduced unrelated materials. In future work, the identity of the anomalous meteorites needs to be determined. To that purpose, this article provides an overview of the find locations of individual meteorites (Tables 2 and 3), so that meteorites can be studied in context and possible foreign strewn fields can later be identified.

Availability of Material

Because individual meteorites cover a wide range of types, all called ''Almahata Sitta,'' the Almahata Sitta strewn field is not unlike an archeological site: meteorites taken out of context can loose their identity and scientific value. It is prohibited to take meteorites out of Sudan without written permission. Local authorities have prosecuted smugglers in the recent past. Material is available for research, upon request, directly from the University of Khartoum, or through the formal collaboration between the University of Khartoum and the SETI Institute in the context of the Almahata Sitta Consortium (http://asima.seti.org/2008TC3/).

Acknowledgments—We thank the many students and staff of the University of Khartoum for their support in recovering the meteorites. The University of Khartoum, Department of Physics and the Faculty of Sciences sponsored the search efforts. Portions of this work were performed at GeoSoilEnviroCARS (Sector 13), Advanced Photon Source (APS), of Argonne National Laboratory. GeoSoilEnviroCARS is supported by the National Science Foundation—Earth Sciences (EAR-0622171), Department of Energy—Geosciences (DE-FG02-94ER14466) and the State of Illinois. Use of the Advanced Photon Source was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357. The authors would like to thank the British Atmospheric Data Centre (BADC) for the UKMO meteorological data. J. M. F. is supported by NASA under the Planetary Geology and Geophysics program through grant NNX09AD92. P. J. is supported by NASA under the Planetary Astronomy program through grant NNX08AO64G.

Editorial Handling—Dr. Donald Brownlee

REFERENCES

Bland P. A., Spurný P., Towner M. C., Bevan A. W. R., Singleton A. T., Bottke W. F., Greenwood R. C., Chesley S. R., Shrbeny L., Borovička J., Ceplecha Z., McClafferty T. P., Vaughan D., Benedix K., Deacon G., Howard K. T., Franchi I. A., and Hough R. M. 2009. An anomalous basaltic meteorite from the innermost main belt. *Science* 325:1525–1527.

Borovička J. and Charvát Z. 2008. 2008 TC_3. *IAU Circular* 8994, edited by Green D. W. E. Cambridge, MA: Central Bureau for Astronomical Telegrams (October 8, 2008).

Borovička J. and Charvát Z. 2009. Meteosat observation of the atmospheric entry of 2008 TC_3 over Sudan and the associated dust cloud. *Astronomy & Astrophysics* 507:1015–1022.

Borovička J. and Kalenda P. 2003. The Morávka meteorite fall: 4. Meteoroid dynamics and fragmentation in the atmosphere. *Meteoritics & Planetary Science* 38:1023–1043.

Britt D. T. and Consolmagno S. J. 2003. Stony meteorite porosities and densities: A review of the data through 2001. *Meteoritics & Planetary Science* 38:1161–1180.

Brown P. 2008. http://aquarid.physics.uwo.ca/~pbrown/usaf/usg282.txt (University of Western Ontario, Canada). Accessed October 18, 2010.

Brown P. G., Hildebrand A. R., Zolensky M. E., Grady M., Clayton R. N., Mayeda T. K., Tagliaferri E., Spalding R., MacRae N. D., Hoffman E. L., Mittlefehldt D. W., Wacker J. F., Andrew Bird J., Campbel M. D., Carpenter R., Gingerich H., Glatiotis M., Greiner E., Mazur M. J., McCausland P. J. A., Plotkin H., and Mazur T. R. 2001. The fall, recovery, orbit, and composition of the Tagish Lake meteorite: a new type of carbonaceous chondrite. *Science* 290:320–325.

Brown P., Pack D., Edwards W. N., ReVelle D. O., Yoo B. B., Spalding R. E., and Tagliaferri E. 2005. The orbit, atmospheric dynamics, and initial mass of the Park Forest meteorite. *Meteoritics & Planetary Science* 39:1781–1796.

Ceplecha Z., Borovička J., Elford W. G., ReVelle D. O., Hawkes R. L., Porubčan V., and Simek M. 1998. Meteor phenomena and bodies. *Space Science Reviews* 84:327–471.

Chesley S., Chodas P., and Yeomans D. 2008. *Asteroid 2008 TC_3 strikes Earth: Predictions and observations agree*. http://neo.jpl.nasa.gov/news/2008TC3.html (NASA/JPL, Near Earth Object Program).

Chodas P. 2008. *2008 TC_3 update*. Minor Planet Mailing List (October 6, 2009, 6:56 P.M. PDT. http://tech.groups.yahoo.com/group/mpml/. Accessed October 18, 2010. University of Arizona: Tucson, AZ.

Cloutis E. A., Hudon P., Romanek C. S., Gaffey M. J., and Hardersen P. S. 2010. Spectral reflectance properties of ureilites. *Meteoritics & Planetary Science* 45. This issue.

Edwards W. N., Brown P. G., and ReVelle D. O. 2004. Bolide energy estimates from infrasonic measurements. *Earth, Moon, and Planets* 95:501–512.

Friedrich J. M., Wignarajah D. P., Chaudhary S., Rivers M. L., Nehru C. E., and Ebel D. S. 2008. Three-dimensional petrography of metal phases in equilibrated L chondrites—Effects of shock loading and dynamic compaction. *Earth and Planetary Science Letters* 275:172–180.

Friedrich J. M., Wolf S. F., Rubmle D., Troiano J., and Gagnon C. J. L. 2010. The elemental composition of Almahata Sitta. *Meteoritics & Planetary Science* 45. This issue.

Gattacceca J., Valenzuela E. M., Leclerc M. D., Rochette P., Suavet C., Jull T., Uehara M., Munayco P., Bourot-Denise M., and Scorzelli R. B. 2009. Atacama: The densest meteorite collection area among hot deserts? (abstract #5083) *Meteoritics & Planetary Science* 44:A75.

Goodrich C. A. 1992. Ureilites: A critical review. *Meteoritics* 27:327–352.

Hildebrand A. R., McCausland P. J. A., Brown P. G., Longstaffe F. J., Russell S. D. J., Tagliaferri E., Wacker J. F., and Mazur M. J. 2006. The fall and recovery of the Tagish Lake meteorite. *Meteoritics & Planetary Science* 41:407–431.

Jenniskens P. 2006. *Meteor showers and their parent comets*. Cambridge, UK: Cambridge University Press. 790 p.

Jenniskens P., Betlem H., Betlem J., Barifaijo E., Schluter T., Hampton C., Laubenstein M., Kunz J., and Heusser G. 1994. The Mbale meteorite shower. *Meteoritics & Planetary Science* 29:246–254.

Jenniskens P., Shaddad M. H., Numan D., Elsir S., Kudoda A. M., Zolensky M. E., Le L., Robinson G. A., Friedrich J. M., Rumble D., Steele A., Chesley S. R., Fitzsimmons A., Duddy S., Hsieh H. H., Ramsay G., Brown P. G., Edwards W. N., Tagliaferri E., Boslough M. B., Spalding R. E., Dantowitz R., Kozubal M., Pravec P., Borovička J., Charvát Z., Vaubaillon J., Kuiper J., Albers J., Bishop J. L., Mancinelli R. L., Sandford S. A., Milam S. N., Nuevo M., and Worden S. P. 2009. The impact and recovery of asteroid 2008 TC_3. *Nature* 12 458, 485–488.

Klekociuk A. R., Brown P. G., Pack D. W., Revell D. O., Edwards W. N., Spalding R. E., Tagliaferri E., Yoo B. B., and Zagari J. 2005. Meteoric dust from the atmospheric disintegration of a large meteoroid. *Nature* 436:1132–1135.

Kohout T., Jenniskens P., Shaddad M. H., and Haloda J. 2010. Inhomogeneity of the 2008 TC_3 asteroid material (Almahata Sitta meteorite) revealed through magnetic susceptibility measurement. *Meteoritics & Planetary Science* 45. This issue.

McGaha J. E., Jacques C., Pimentel E. et al. 2008. 2008 TC_3. In *Minor planet electronic circular 2008-T50*, edited by Wiliams G. V. (Issued October 6, 14:59 UT). Cambridge, MA: Minor Planet Center, Smithsonian Astrophysical Observatory. p. 1–1.

Rumble D., Zolensky M. E., Friedrich J. M., Jenniskens P., and Shaddad M. H. 2010. The oxygen isotope composition of Almahata Sitta. *Meteoritics & Planetary Science* 45. This issue.

Sabbah H., Morrow A. L., Jenniskens P., and Shaddad M. H. 2010. Polycyclic aromatic hydrocarbons in asteroid 2008 TC_3: Dispersion of organic compounds inside asteroids. *Meteoritics & Planetary Science* 45. This issue.

Sandford S. A., Milam S. N., Nuevo M., Jenniskens P., and Shaddad M. H. 2010. The mid-infrared transmission spectra of multiple stones from the Almahata Sitta meteorite. *Meteoritics & Planetary Science* 45. This issue.

Swinbank R. and O'Neill A. A. 1994. Stratosphere-troposphere data assimilation system. *Monthly Weather Review* 122:686–702. http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__dataent_ASSIM.

Weisberg M. K., Smith C., Benedix G., Herd C. D. K., Righter K., Haack H., Yamaguchi A., Chennaoui Aoudjehane H., and Grossman J. N. 2009. Almahata Sitta. The Meteoritical Bulletin, No. 96. *Meteoritics & Planetary Science* 44:1355–1397.

Zolensky M., Herrin J., Mikouchi T., Ohsumi K., Friedrich J., Steele A., Rumble D., Fries M., Sandford S., Milam S., Hagiya K., Takeda H., Satake W., Kurihara T., Colbert M., Hanna R., Maisano J., Ketcham R., Goodrich C., Le L., Robinson G.-A., Martinez J., Ross K., Jenniskens P., and Shaddad M. 2010. Mineralogy and petrography of the Almahata Sitta ureilite. *Meteoritics & Planetary Science* 45. This issue.