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The fall, recovery, and classification of the Park Forest meteorite

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Abstract–On the night of March 26, 2003, a large meteorite broke up and fell upon the south suburbs of Chicago. The name Park Forest, for the village that is at the center of the strewnfield, has been approved by the nomenclature committee of the Meteoritical Society. Satellite data indicate that the bolide traveled from the southwest toward the northeast. The strewnfield has a southeast-northwest trend; however, this is probably due to the effects of strong westerly winds at high altitudes. Its very low ^{56}Co and very high ^{60}Co activities indicate that Park Forest had a preatmospheric mass that was at least ~900 kg and could have been as large as ~7×10^3 kg, of which only ~30 kg have been recovered. The average compositions of olivine and low-Ca pyroxene, $Fa_{24.7 \pm 1.1}$ and $Fs_{20.8 \pm 0.7}$, respectively, and its bulk oxygen isotopic composition, $\delta^{18}O = +4.68‰$, $\delta^{17}O = +3.44‰$, show that Park Forest is an L chondrite. The ferromagnesian minerals are well equilibrated, chondrules are easily recognized, and maskelynite is mostly ≤50 μm across. Based on these observations, we classify Park Forest as type 5. The meteorite has been strongly shocked, and based on the presence of maskelynite, mosaicism and planar deformation features in olivine, undulatory extinction in pyroxene, and glassy veins, the shock stage is S5. The meteorite is a monomict breccia, consisting of light-colored, angular to rounded clasts in a very dark host. The light and dark lithologies have essentially identical mineral and oxygen isotopic compositions. Their striking difference in appearance is due to the presence of a fine, pervasive network of sulfide veins in the dark lithology, resulting in very short optical path lengths. The dark lithology probably formed from the light lithology in an impact that formed a sulfide-rich melt and injected it into cracks.

INTRODUCTION

On March 26, 2003, at about 11:50 P.M., a bright fireball was observed over north-central U.S.A., visible from parts of Illinois, Indiana, Michigan, and Missouri. Detonations loud enough to awaken residents were heard in the southern suburbs of Chicago. Meteorites shattered windows and pierced roofs in and around Park Forest, Illinois (41°29′05″N, 87°40′45″W)—where S. B. Simon resides—a suburb ~50 km south of downtown Chicago. Police were called throughout the night, and they took specimens into custody as evidence. Residents were asked to bring in specimens as well, and the Park Forest police station became a central location where meteorite finders, collectors, dealers, scientists, and reporters came together. It soon became apparent that Park Forest was at the center of a strewnfield that extends from Crete, Illinois in the south, to the extreme southern edge of Olympia Fields, Illinois in the north, a distance of ~9.5 km. This is the most densely populated region to be hit by a meteorite shower in modern times. Hundreds of fragments have been recovered, ranging from a few grams up to 5.26 kg. The name Park Forest and its classification as an L5 chondrite have been approved by the nomenclature committee of the Meteoritical Society (Russell et al. 2003). The type material, a 545 g fragment that hit the Park Forest fire station, is housed at The Field Museum, Chicago. In this study, we report the recovery,

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petrography, and mineral chemistry of Park Forest along with its bulk cosmogenic radionuclide abundances and oxygen isotopic composition. The preliminary results of this study were reported by Simon et al. (2003).

ANALYTICAL METHODS

Polished thin sections from four fragments of the meteorite were studied optically and with a JEOL JSM-5800LV scanning electron microscope (SEM) equipped with an Oxford/Link ISIS-300 energy-dispersive X-ray analysis system. Quantitative wavelength-dispersive analyses were obtained with a Cameca SX-50 electron microprobe operated at 15 kV with a beam current of 50 nA. Data were reduced via the modified ZAF correction procedure PAP (Pouchou and Pichoir 1984). For the determination of oxygen isotopic composition, oxygen was liberated from chips of the meteorite by reaction with bromine pentafluoride (Clayton and Mayeda 1963) and was mass-analyzed as O_2 (Clayton and Mayeda 1983). For the measurement of cosmogenic radionuclides' activity, a 232 g individual specimen was counted for 7727 min on a high-efficiency NaI(Tl) multiparameter gamma spectrometer. The instrument was calibrated using a series of mockups of freshly fallen meteorites as in the methods of Edwards et al. (1982) and Evans and Reeves (1987).

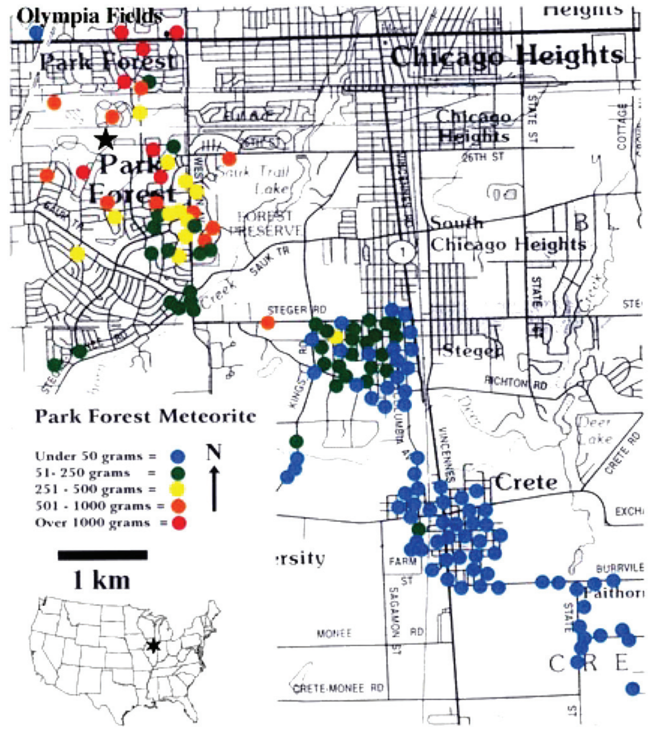

Fig. 1. Locations of documented meteorite finds within the strewnfield, color-coded by sizes of individual stones. Many more fragments have been found in Crete (lower right) than can be shown here. The star (upper left) indicates the location of the home of S. B. Simon.

RESULTS

Hand Sample Recovery and Description

Fragments that hit roofs, windows, and cars were recovered almost immediately, without exposure to the rainfall of March 28. Others were found over the next few weeks on driveways, in streets, and in yards. Fields, streets, and roofs were searched. Some stones, especially those that hit streets and sidewalks, shattered upon impact while those that fell on unpaved grassy areas were partially to completely embedded in the ground. A map of the strewnfield is shown in Fig. 1, with the known meteorite recovery locations indicated. The total weight of these documented samples is ~18 kg. Other specimens were sold by the finders before their locations could be recorded, and probably some have not been reported at all. We estimate that at least ~30 kg have been recovered. In addition, along much of the eastern border of Park Forest, there is a heavily wooded forest preserve. Meteorites have been found immediately to the south, west, and north of the preserve—some must have fallen within it but we have no reports of any specimens being recovered from within the forest preserve. Within another gap in the strewnfield, slightly northwest of the forest preserve, sits the home of S. B. Simon (indicated with a star in Fig. 1).

The most numerous fragments, more than are indicated in Fig. 1, were found in Crete, Illinois, the southern end of the strewnfield. These also tend to be the smallest. Most of the ~40 documented fragments that fell in Park Forest are between 100 and 1000 g. The two largest specimens, 5.26 and 2.67 kg, fell in Olympia Fields, and their impact sites define the northern edge of the strewnfield. Thus, there is a general trend of increasing fragment size from southeast to northwest. This is related to the trajectory of the bolide, although data from satellites indicate that it traveled from the southwest to the northeast (Brown et al. Forthcoming). The meteorite broke up in the atmosphere, and the fragments encountered strong westerly winds as they fell. The smallest pieces were deflected the furthest eastward from the trajectory, and the largest pieces, carrying more momentum, were deflected the least. Several of the largest specimens that were recovered pierced roofs and entered houses. One hit a window sill, then bounced across the room and broke a mirror (Fig. 2), narrowly missing a person who had been sleeping in the room. The largest specimen known thus far was not found until mid-April, embedded in the front lawn of an Olympia Fields home.

Recovered specimens range from nearly fusion crust-free to completely crusted. Many are fist-sized and rounded, with only patches of fusion crust. From the fresh surfaces visible on fusion crust-free pieces, Park Forest is clearly a breccia with light gray clasts in a very dark matrix. Most pieces,

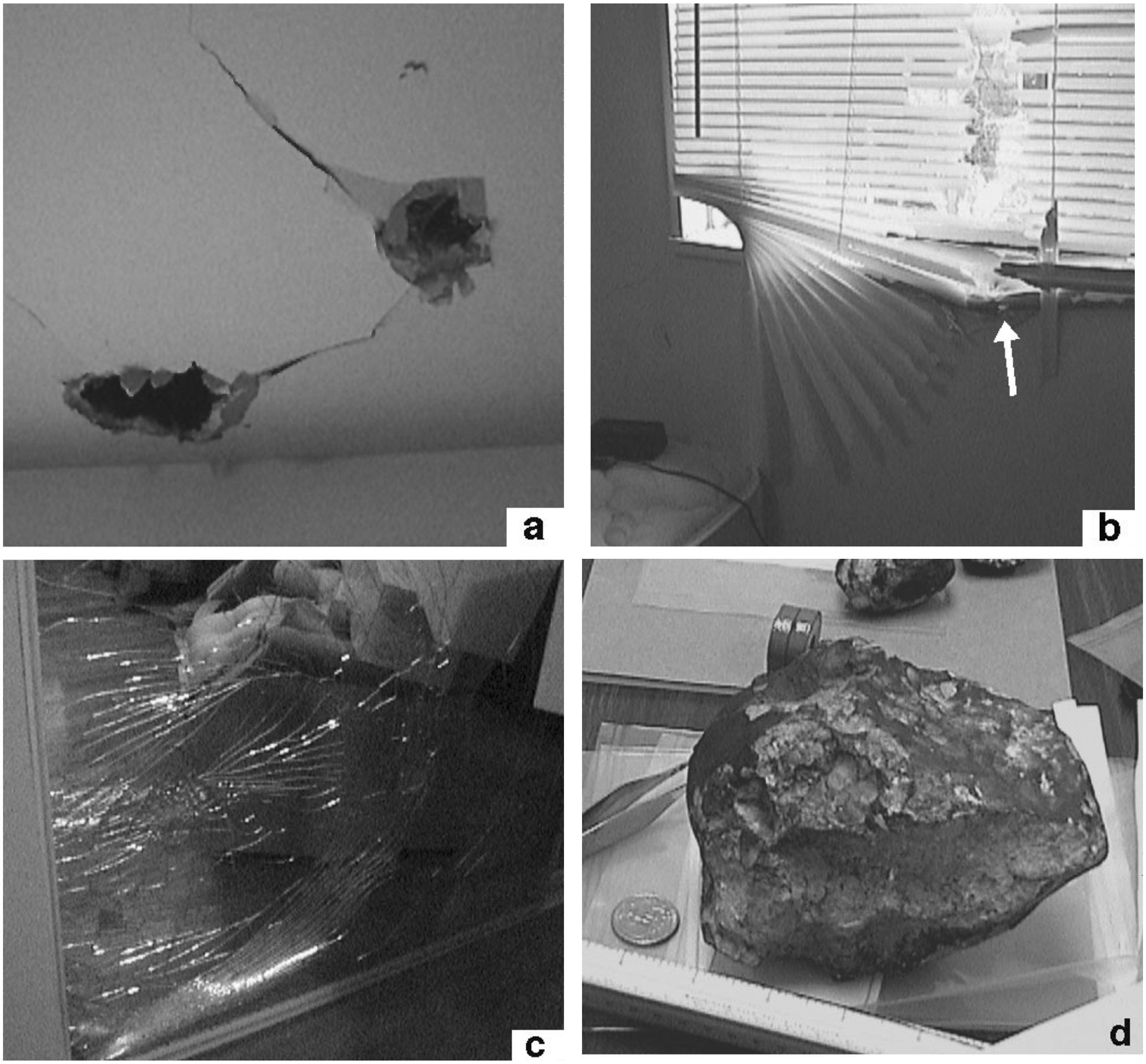

Fig. 2. Damage to a bedroom in Park Forest caused by a 2.5 kg stone, one of the largest specimens found: a) holes in the ceiling; b) damage to window blinds and sill. Note impact crater in window sill, indicated by the arrow; c) broken mirror on wall opposite window. The meteorite bounced across the floor; d) the stone that did the damage.

especially the larger ones, are dominated by the light lithology (e.g., Fig. 2d), some have both lithologies, and a few, generally small pieces, consist of only the dark lithology. The light clasts may be angular or rounded, but in all cases, contacts between the light and dark material are sharp (Fig. 3). In some cases (e.g., Fig. 3a), there is much dark material enclosing the lighter clasts. In other cases (e.g., Fig. 3b), there are only thin veins of dark material between clasts of light material. Flecks of metal and sulfide can be seen with the naked eye throughout both lithologies. Metal is heterogeneously distributed, as some specimens can hold a magnet while others barely attract a magnet at all.

Optical and Electron Petrography

Polished thin sections of both the light and dark lithologies, and a section sampling a contact between the light lithology and a melt vein were examined. The light lithology has a texture typical of a brecciated ordinary chondrite. It is dominated by anhedral olivine that is mostly between 80 and 200 µm across, but there are also many single crystals 400–600 µm across. A backscattered electron image of a representative area is shown in Fig. 4a. Note the lack of fine-grained matrix and the rather fine grain sizes (~50 µm) of maskelynite and high-Ca pyroxene, which coarsen with

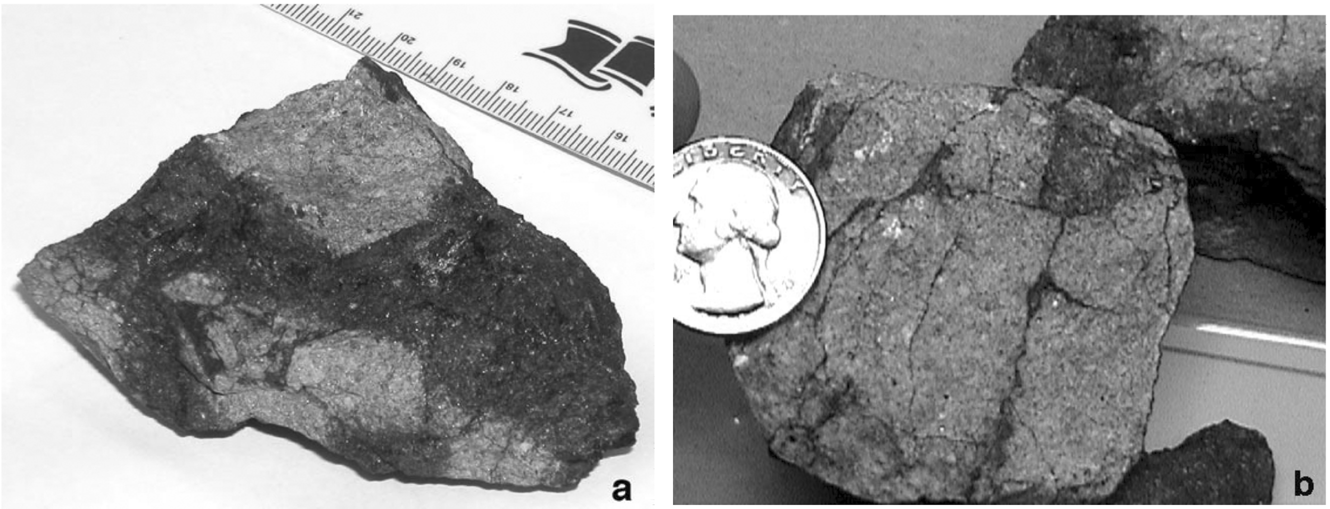

Fig. 3. Individuals that show the brecciated texture of the meteorite: a) a 232 g specimen used for measurement of cosmogenic radionuclides, showing light, angular clasts in a black matrix. The small divisions on the scale are mm; b) a small hand sample showing light clasts separated by thin veins of dark material, probably shock melt.

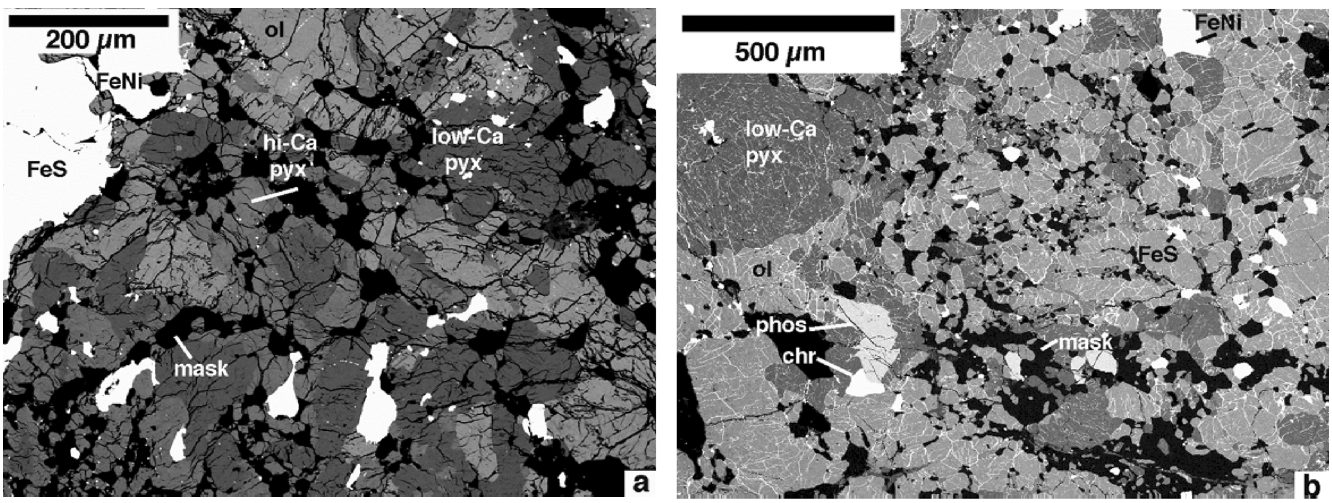

Fig. 4. Backscattered electron images of representative areas in the light lithology (a) and dark lithology (b) of Park Forest. ol = olivine, low-Ca pyx = low-Ca pyroxene, hi-Ca pyx = high-Ca pyroxene, mask = maskelynite, chr = chromite, and phos = phosphate.

increasing petrologic type. Note also the absence of sulfide veins within the crystals. Shock features include dark, sulfide-rich, glassy veins that cross-cut and separate clasts, mosaicism and planar deformation features in olivine, undulatory extinction in pyroxene, and conversion of plagioclase to maskelynite. The abundance of opaque phases varies from section to section, but all sections contain FeNi metal, FeS, and chromite. Minor amounts of high-Ca pyroxene, chromite, and Ca-phosphate (merrillite ± chlorapatite) are also present in each section.

In transmitted light, the dark lithology, with its many opaque areas, looks very different from the light lithology but low-magnification (<~50×) backscattered electron views are not strikingly different because the two lithologies have very similar mineralogy. However, at higher magnification (Fig. 4b), a pervasive network of fine sulfide veins can be seen in the dark lithology. The absence of veins in the light lithology and their presence in the dark lithology extends to their chondrules (Fig. 5). Both lithologies contain chondrules and chondrule fragments that retain their original textures except that glass is not preserved. Chondrules are easily recognized but their boundaries with the host meteorite, in most cases, are not very sharp. Diameters range from ~600 µm to 1.3 mm. Barred and porphyritic olivine chondrules are the most abundant, followed by olivine-free, granular pyroxene chondrules.

Figure 6 is a backscattered electron image of a contact between a clast of the light lithology and an optically dark,

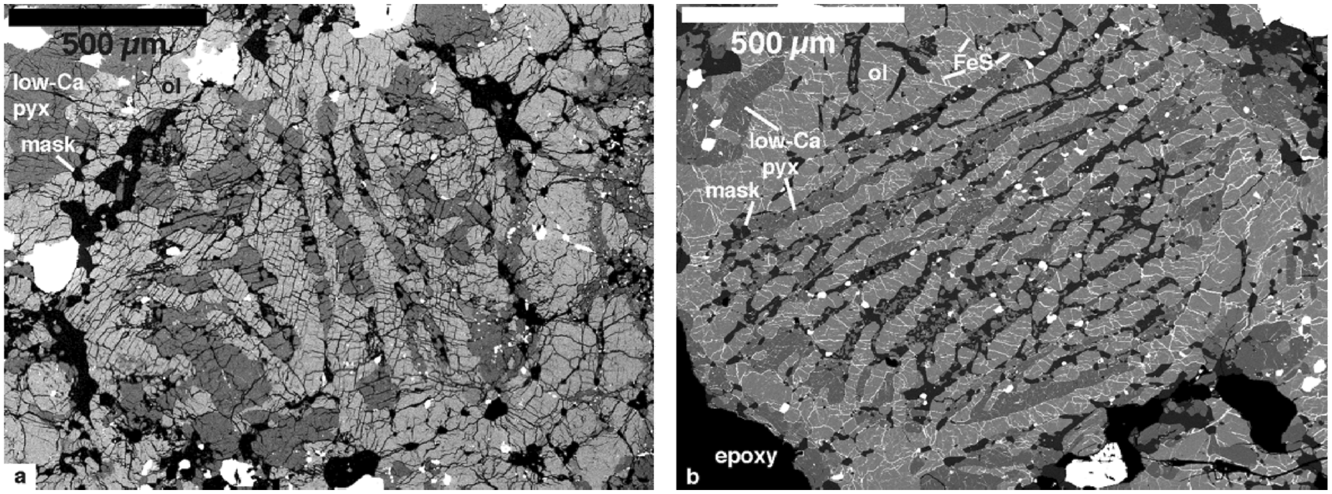

Fig. 5. Backscattered electron images of barred olivine chondrules in Park Forest: a) light lithology; b) dark lithology. Note the fine sulfide veins in olivine. The abbreviations are as used previously.

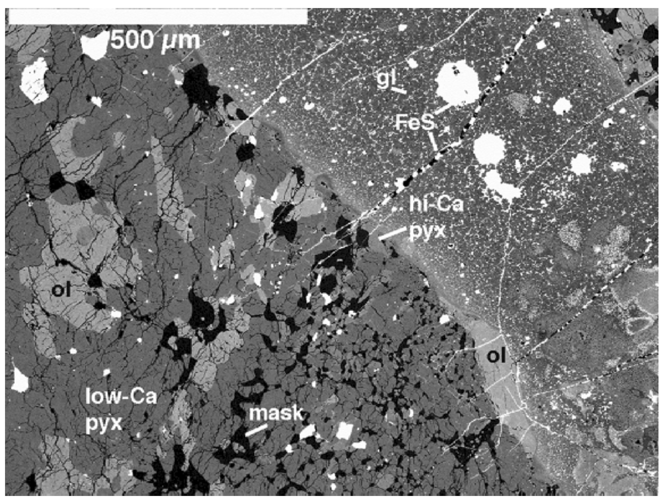

Fig. 6. Backscattered electron image of a contact between the light lithology (lower left half of image) and sulfide-rich shock melt. gl = glass; the other abbreviations are as used previously.

glassy, sulfide-rich shock vein, like those present in the hand sample shown in Fig. 3b. Some olivine grains formed FeO-rich reaction rims with the melt. Note the sharpness of the vein/clast contact and the limited penetration (~100 µm) of fine sulfide veins into the light lithology. The high pressure phases ringwoodite and majorite, commonly found in strongly shocked L chondrites, have not been observed in Park Forest.

Mineral Chemistry

We analyzed randomly selected olivine and pyroxene grains by electron microprobe to determine their compositions and degree of equilibration. Results are summarized in Figs. 7–9, and representative analyses are given in Table 1. The compositions are quite uniform; grains within chondrules have the same compositions as those not in chondrules.

Average fayalite (Fa) contents for two sections of the light lithology (24.7 ± 1.1, 24.5 ± 0.7) and one of the dark (24.9 ± 1.3) are all within error of each other. The histograms of the compositions (Fig. 7) are also similar, with most analyses in the Fa_{23-25} range. We have not found any unequilibrated clasts like those in Itawa Bhopji, which was classified by Bhandari et al. (2002) as an L3–5 chondrite. As shown in Table 1, minor element contents (Al_2O_3, CaO, TiO_2) are very low and MnO contents are between 0.4 and 0.5 wt%. These values are quite typical for olivine in equilibrated ordinary chondrites (Brearley and Jones 1998).

Low-Ca pyroxene compositions (Fig. 8) are also well equilibrated. For the same sections in which olivine was analyzed, the average ferrosilite (Fs) contents of the pyroxene

Table 1. Representative analyses of olivine and low-Ca pyroxene in Park Forest.[a]

	1	2	3	4	5	6	7	8
MgO	39.13	38.81	38.88	38.49	29.19	28.83	28.84	29.15
SiO_2	38.43	38.22	38.07	38.01	55.77	55.76	55.02	55.58
Al_2O_3	BDL	BDL	BDL	BDL	0.17	0.16	0.16	0.14
CaO	BDL	BDL	BDL	BDL	0.84	0.91	0.97	0.85
TiO_2	BDL	BDL	BDL	0.06	0.12	0.26	0.16	0.19
MnO	0.44	0.44	0.42	0.41	0.45	0.48	0.47	0.49
FeO	22.21	22.48	23.17	22.75	13.89	13.96	13.74	13.62
Total	100.21	99.95	100.54	99.72	100.43	100.36	99.36	100.02
	Cations per 4 Ox				Cations per 6 Ox			
Si	0.997	0.996	0.990	0.995	1.987	1.989	1.983	1.987
Mg	1.513	1.507	1.507	1.501	1.549	1.533	1.549	1.553
Al	0	0	0	0	0.007	0.007	0.007	0.006
Ca	0	0	0	0	0.032	0.035	0.038	0.033
Ti	0	0	0	0.001	0.003	0.007	0.004	0.005
Mn	0.010	0.010	0.009	0.009	0.014	0.015	0.014	0.015
Fe	0.482	0.490	0.504	0.498	0.414	0.416	0.414	0.407
Total	3.002	3.003	3.010	3.004	4.006	4.002	4.009	4.006
Mol% Fa or Fs	24.2	24.5	25.1	24.9	20.7	21.0	20.7	20.4

[a]Columns 1–3: olivine, light lithology; column 4: olivine, dark lithology; columns 5–6: low-Ca pyroxene, light lithology; columns 7–8: low-Ca pyroxene, dark lithology. BDL = below detection limit of 0.011 wt% Al_2O_3, 0.032 wt% CaO, or 0.040 wt% TiO_2.

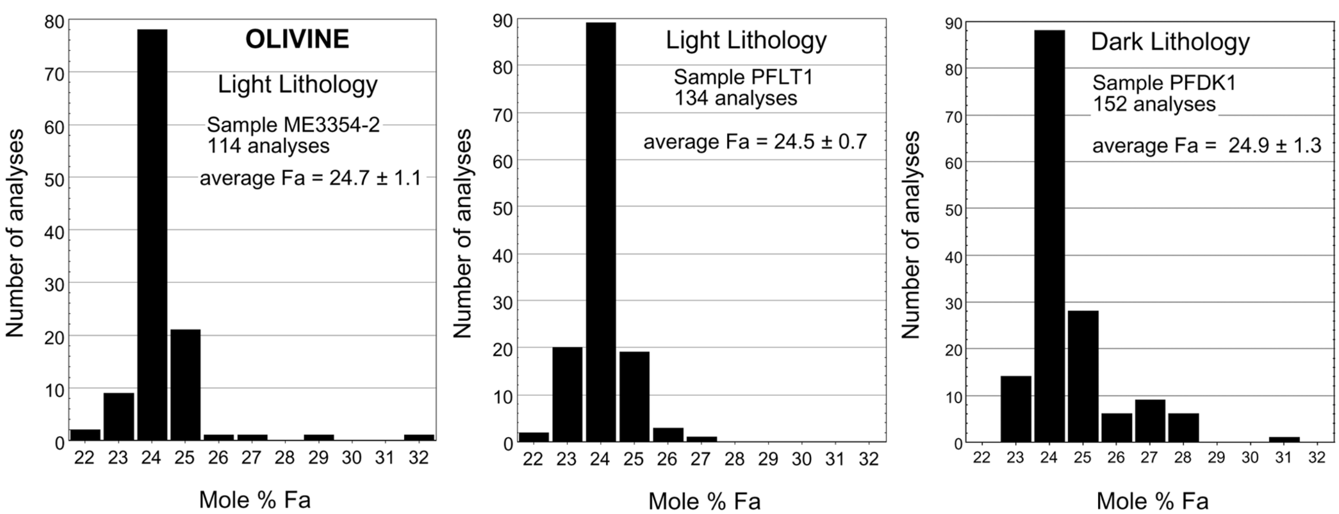

Fig. 7. Histograms showing the distribution of olivine compositions in Park Forest.

are 21.0 ± 0.7, 20.7 ± 0.3, and 20.8 ± 0.9, all within error of each other. Most analyses fall in a very narrow range, Fs_{20-21}. The wollastonite components are 1–2 mol%, typical of low-Ca pyroxene in ordinary chondrites (Brearley and Jones 1998).

In Fig. 9, the average Fa and Fs contents of Park Forest olivine and pyroxene in the light and the dark lithologies are compared to the recognized ranges for equilibrated ordinary chondrites. The results for both lithologies fall well within the ranges of the L chondrites.

The compositions of the minor phases are also typical of ordinary chondrites, especially the L group. The average composition of high-Ca pyroxene in Park Forest is $En_{48.2}Wo_{43.6}Fs_{8.2}$, with Na_2O, Al_2O_3, TiO_2 and MnO contents like those previously reported for ordinary chondrites (Brearley and Jones 1998). The average composition of maskelynite is $Ab_{81}An_{10}Or_9$, slightly less sodic and more potassic than the average composition for plagioclase in L chondrites, $Ab_{84}An_{10}Or_6$ (Brearley and Jones 1998). The compositions of chromite in Park Forest are within the range of those reported for L chondrites, as are those of merrillite and chlorapatite (Brearley and Jones 1998; Jones, personal communication). Representative analyses of glass from the sulfide-rich vein shown in Fig. 6 are given in Table 2. The composition appears to be a mixture of olivine, pyroxene, and feldspar, and is very close to the average composition of L-group chondrites (Rubin et al. 1981).

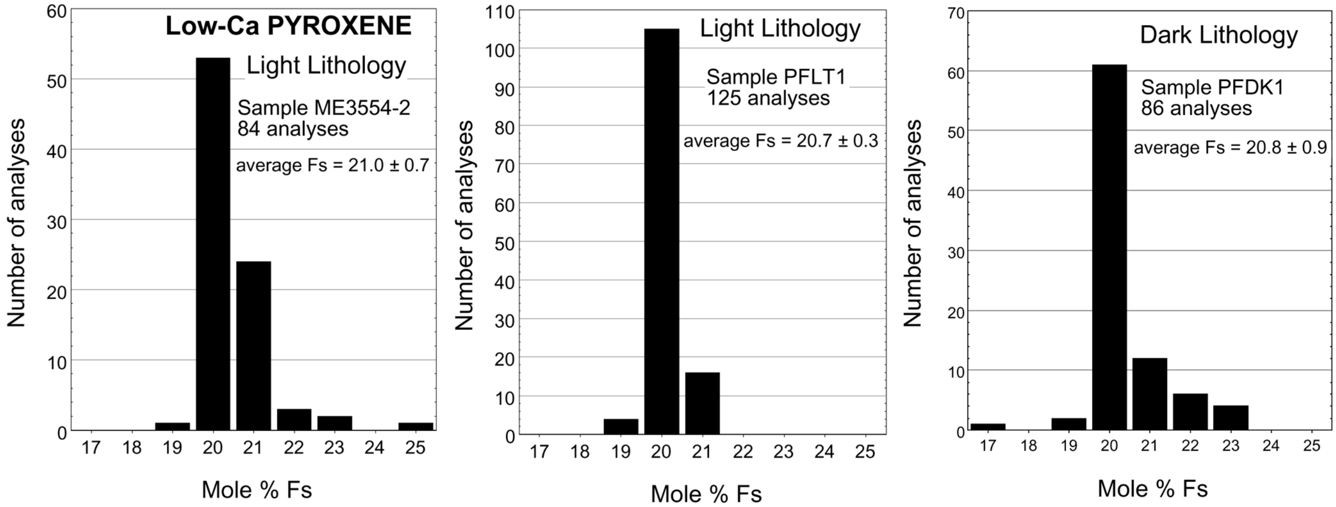

Fig. 8. Histograms showing the distribution of low-Ca pyroxene compositions in Park Forest.

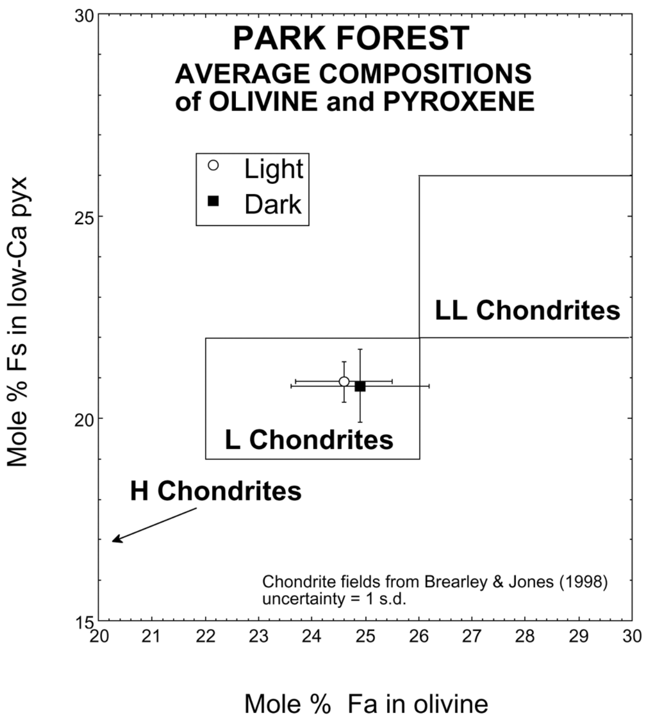

Fig. 9. Comparison of the average low-Ca pyroxene and olivine compositions in the light and dark lithologies of Park Forest with ranges observed in equilibrated ordinary chondrites. The H chondrites are just outside the range of the plot.

Oxygen Isotopic Analysis

Using separate aliquots of each, we determined the bulk oxygen isotopic compositions of both the light and the dark lithologies. The two lithologies have virtually identical oxygen isotopic compositions. The composition of the light lithology is: $\delta^{18}O$ = +4.65‰, $\delta^{17}O$ = +3.44‰. The composition of the dark lithology is $\delta^{18}O$ = +4.72‰, $\delta^{17}O$ = +3.44‰. These data plot on the ordinary chondrite trend (Fig. 10), and, with a 2σ uncertainty of ~0.15‰, are within error of each other and of the average value for L chondrite falls ($\delta^{18}O$ = +4.70‰, $\delta^{17}O$ = +3.52‰) obtained from the data of Clayton et al. (1991).

Table 2. Analyses of glass in vein.

	1	2
Na_2O	0.92	0.66
MgO	30.08	29.12
Al_2O_3	3.12	3.39
SiO_2	49.16	49.92
CaO	2.37	1.79
Cr_2O_3	0.66	0.77
TiO_2	0.11	0.16
MnO	0.46	0.40
FeO	12.16	12.70
Total	99.04	98.91

Cosmogenic Radionuclides

A 232 g specimen (Fig. 3a) that was recovered the night of the shower was used for measurement of cosmogenic radionuclide activities. Counting began less than 72 hr after the fall. The results are summarized in Table 3. Both ^{22}Na and ^{26}Al activities are at the high ends of the normal ranges for L chondrites. The $^{22}Na/^{26}Al$ ratio expected in an L chondrite varies as a function of the solar cycle, and ranges from ~1.0–1.6. The observed value of 1.38 ± 0.11 is slightly higher than the value of ~1.2 that would be expected for an L chondrite falling in early 2003 (Bhandari et al. 2002). The average for L chondrites over a solar cycle is 1.35, regardless of the size of the meteoroid (Bhandari et al. 2002).

The ^{56}Co activity is very low (essentially zero), indicating that the sample contains very little material that was exposed to solar cosmic rays. Because it mainly forms at the surfaces of

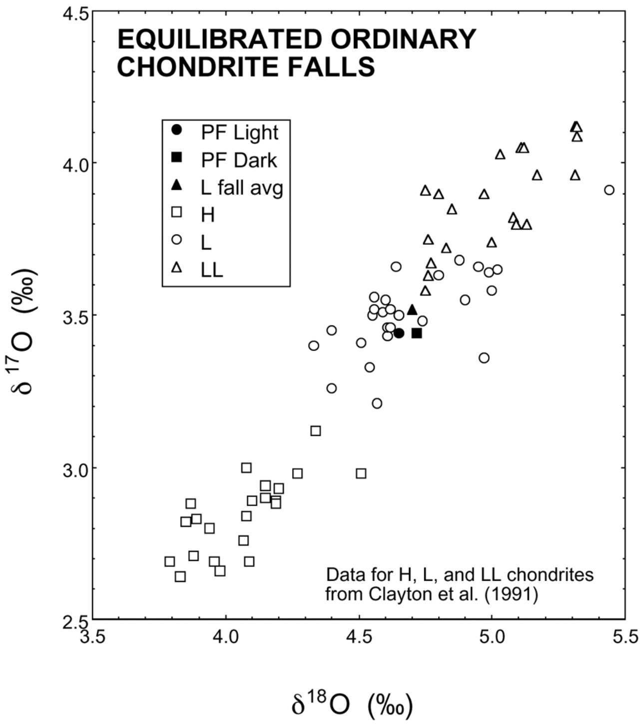

Fig. 10. Oxygen isotopic compositions of the light and dark lithologies of Park Forest. They are virtually identical to each other and to the average of L chondrite falls, and distinct from the H and LL chondrites.

bodies, ^{56}Co activity is typically low in interior pieces of meteorites that had large preatmospheric masses. In contrast, ^{60}Co, which forms by neutron capture and the activity of which increases with depth in a meteoroid, exhibits a high activity in Park Forest. Thus, both the ^{56}Co and ^{60}Co measurements point to a large preatmospheric size for Park Forest. The production rate of ^{60}Co as a function of depth in spherical chondrites of different radii has been calculated by Eberhardt et al. (1963) and Spergel et al. (1982). From these calibration curves, we estimate that the minimum radius consistent with the observed ^{60}Co activity of 66 dpm/kg is ~35–40 cm. Assuming a density of 3.4 g/cc, a recently reported average for L-group chondrites (Wilkison and Robinson 2000), this corresponds to a minimum preatmospheric mass for Park Forest in the 600–1000 kg range. From the models of Eberhardt et al. (1963) and Bhandari et al. (1993), the ^{60}Co and ^{26}Al activities, respectively, are best matched by irradiation in a 900 kg meteoroid (~40 cm radius). This is only a lower limit, as the high ^{60}Co activity could not be attained in a much smaller body because too many neutrons would escape the meteoroid without being captured, but it could be consistent with derivation from a shallower depth in a larger body. A significantly larger mass would be inconsistent with the high ^{26}Al activity we observed, but ^{26}Al is not as sensitive to depth as ^{60}Co. Brown et al. (Forthcoming) conclude that the most probable preatmospheric mass for Park Forest was $(11 \pm 3) \times 10^3$ kg, from their entry model for the meteoroid and interpretation of the light curve. Their data are

Table 3. Cosmogenic radionuclides in Park Forest.[a]

Radionuclide	Half-life	Activity (dpm/kg)
^{22}Na	2.6 yr	95 ± 5
^{26}Al	0.73 Myr	69 ± 4
^{56}Co	77 da	~0.1
^{60}Co	5.3 yr	66 ± 3
^{22}Na/^{26}Al = 1.38 ± 0.11		

[a]dpm = decays per minute. Also detected but not quantified are: ^{7}Be ($t_{1/2}$ = 53 da), ^{46}Sc (84 da), ^{48}V (16 da), and ^{54}Mn (312 da).

not consistent with a mass as low as 1000 kg. Although not the best fit for either the radionuclide models or the energy curves, a preatmospheric mass of ~6–7 × 10^3 kg would probably be permissible by both methods.

DISCUSSION

Classification of Park Forest

Most ordinary chondrites belong to one of the fairly well-defined H, L, or LL groups. As shown in Fig. 9, on the basis of average olivine and low-Ca pyroxene compositions, there is more of a gap between the H and L groups than there is between the L and LL groups, and an intermediate (L/LL) group has been proposed (Rubin 1990). The average olivine and low-Ca pyroxene in both the light and dark lithologies fall within the range of the L chondrites (Fig. 9). The overall average Fa content of olivine in Park Forest (400 analyses) is 24.7 ± 1.1, and the average Fs content of the low-Ca pyroxene (295 analyses) is 20.8 ± 0.7. On the basis of its average olivine and low-Ca pyroxene compositions and its bulk oxygen isotopic composition (Figs. 9 and 10, respectively), Park Forest is an L chondrite. Assigning a petrologic type is more subjective. In applying the criteria of Van Schmus and Wood (1967), we note that mineral compositions are clearly equilibrated and the chondrules are not glassy, so it is not a type 3. With increasing grade, high-Ca pyroxene and plagioclase (or maskelynite) become coarser-grained and chondrules become less distinct. Because Park Forest has highly equilibrated silicate phases, readily recognized chondrules only partially integrated with the host meteorite and relatively fine (mostly ≤~50 μm) maskelynite and high-Ca pyroxene, we classify it as an L5. The chondrules are too distinct and the maskelynite is too fine-grained for classification as a type 6. It is also strongly shocked, based on the presence of shock veins, mosaicism and planar deformation features in olivine, and conversion of plagioclase to maskelynite. According to the criteria of Stöffler et al. (1991), the shock stage is S5.

Formation of Light/Dark Structure

A feature of Park Forest that is not common to all L chondrites is its structure of light-colored clasts in a very dark matrix. As described by Britt and Pieters (1994), there are two dominant morphologies of metal and troilite grains that occur in black chondrites. Both are found in Park Forest. One morphology is fine, typically ~2 µm, grains randomly dispersed within silicates. In Park Forest, this mainly occurs in the thin, glassy veins of shock melt (e.g., Fig. 6). The other major morphology, and the dominant one in Park Forest, is fine networks of pervasive veins, mostly consisting of FeS, filling many cracks within and between grains. The veins are found in the relatively coarse dark lithology (e.g., Figs. 4b and 5b) and are the reason for its very dark appearance. Both the veins and the dense clouds of fine grains result in very short optical path lengths for light rays entering mineral grains in the dark lithology, allowing few to escape (Britt and Pieters 1994).

The presence of sulfide veins in the dark lithology and their absence in the light lithology is the main difference between the two lithologies. Their mineral compositions and bulk oxygen isotopic compositions are the same within error. The dark lithology was probably formed from the light material in an impact on the parent body that mobilized sulfides but did not extensively melt the silicates.

CONCLUSIONS

The meteorite that broke up and fell over the suburbs south of Chicago on March 26, 2003 had a large preatmospheric mass, at least 900 kg and possibly as large as 7×10^3 kg. Only ~30 kg have been recovered so far. The name Park Forest has been approved by the nomenclature committee of the Meteoritical Society. Based on its average olivine ($Fa_{24.7 \pm 1.1}$) and low-Ca pyroxene ($Fs_{20.8 \pm 0.7}$) compositions, Park Forest is an L chondrite. From the homogeneity of the silicate phases, the degree of preservation of the chondrules, and the grain sizes of maskelynite and high-Ca pyroxene, Park Forest is type 5. The presence of maskelynite, shock veins, and mosaicism indicate the shock stage is S5 (Stöffler et al. 1991). Park Forest is a monomict breccia with light clasts in a dark matrix. The matrix is black due to a fine network of veins of FeS, a feature previously seen in other shocked chondrites. The dark and light lithologies have virtually identical mineralogical and bulk oxygen isotopic compositions, and we conclude that the dark lithology was formed from the light one in an impact event that mobilized a sulfide-rich melt, which filled cracks and yielded very short optical path lengths and a very dark appearance.

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