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The Burnwell, Kentucky, low iron oxide chondrite fall: Description, classification and origin

SARA S. RUSSELL[1]*, TIMOTHY J. MCCOY, EUGENE JAROSEWICH AND RICHARD D. ASH[2]

Department of Mineral Sciences, MRC 119, U. S. Museum of Natural History, Smithsonian Institution, Washington DC 20560, USA
[1]Present address: Department of Mineralogy, The Natural History Museum, Cromwell Road, London, SW7 5BD, U.K.
[2] Also at Geophysical Laboratory, Carnegie Institution of Washington, 5251 Broad Branch Road NW, Washington DC 20015, USA
*Correspondence author's e-mail address: sarr@nhm.ac.uk

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Abstract–The Burnwell, Kentucky, meteorite fell as a single stone on 1990 September 4. The Burnwell meteorite has lower Fa in olivine (15.8 mol%), Fs in orthopyroxene (13.4 mol%), Co in kamacite (0.36 wt%), FeO from bulk chemical analysis (9.43 wt%), and $\Delta^{17}O$ (0.51 ± 0.02‰), and higher Fe, Ni, Co metal (19.75 wt% from bulk wet chemical analysis) than observed in H chondrites. The Burnwell meteorite plots on extensions of H-L-LL chondrite trends for each of these properties towards more reducing compositions than in H chondrites. Extensions of this trend have been previously suggested in the case of other low-FeO chondrites or silicate inclusions in the IIE iron Netschaëvo, but interpretation of the evidence in these meteorites is complicated by terrestrial weathering, chemical disequilibrium or reduction. In contrast, the Burnwell meteorite is an equilibrated fall that exhibits no evidence for reduction. As such, it provides the first definitive evidence for extension of the H-L-LL ordinary chondrite trend beyond typical H values towards more reducing compositions.

INTRODUCTION

This paper presents details on the fall, petrology, chemistry and O isotopic composition of a new chondrite fall from Burnwell, Kentucky. The Burnwell meteorite is unusual in many of its properties and we briefly discuss its classification, relationship to other meteorites and possible origin.

FALL

On 1990 September 4, at 3:45 P.M. E.D.T., a meteorite fell through the roof and floor of the front porch of the home of Arthur and Frances Pegg near the town of Burnwell, Kentucky. The coordinates of the site are 37°37'19" N, 82°14'14" W. The Peggs report that the meteorite made a sound like a helicopter that changed pitch as it approached, and it hit the house with an explosive sound. Eyewitness accounts gathered by the Peggs at the time of the fall suggest that the meteorite approached from the south-southwest. The following day, a single 1.504 kg, roughly brick-shaped stone measuring 15.5 × 7 × 5 cm was recovered by Mr. Pegg from an enclosed area below the porch (Fig. 1). The meteorite was almost entirely covered (95%) with fusion crust at the time of its recovery. On its surface several patches of lacquer and a small amount of paint are visible from cans that it hit in the area beneath the porch. This stone was acquired for the Smithsonian during a visit to the area by Timothy McCoy in 1997 January and is cataloged as USNM 6847. The interior is medium gray in color with distinct chondrules and abundant metal grains visible on the cut surface. Rare dark clasts a few millimeters in diameter are also visible.

DESCRIPTION

Petrology

Polished thin sections (USNM 6847-1 and -2) from the interior of the Burnwell meteorite were examined in transmitted and reflected light in an optical microscope. A modal analysis was acquired by point counting on a combined Fe + S + Si x-ray dot map obtained by using a JEOL 840A scanning electron microscope. Quantitative analyses of mafic silicates were conducted by using a JEOL JXA 8900 electron microprobe, with a 1 μm diameter beam, 15 keV accelerating voltage and 20 nA beam current for analyses.

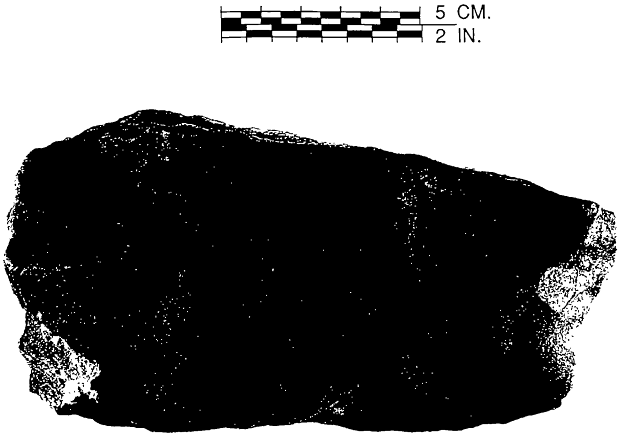

FIG. 1. The main mass of the Burnwell meteorite.

The Burnwell meteorite has a well-defined chondritic texture. It is classified as petrologic type 4 based on the presence of sharply delineated chondrules, abundant polysynthetically striated pyroxene, microcrystalline mesostasis, lack of chondrule glass and equilibrated olivine compositions. Measurement of the diameters of all of the chondrules in a selected area of USNM 6847-2 (N = 51) yields an average of 0.36 ± 0.18 mm and a range of 0.12–0.94 mm, which is similar to that for H chondrites (Grossman *et al.*, 1988).

The mean olivine composition is $Fa_{15.8 \pm 0.2}$ (N = 79, range 15.5–16.2) and low-Ca pyroxene composition is $En_{85.9 \pm 0.7}Fs_{13.4 \pm 0.7}Wo_{0.7 \pm 0.2}$ (N = 98, Fs range 12.4–15.2) (Tables 1 and 2). Histograms of olivine and low-Ca pyroxene compositions are shown in Fig. 2, which illustrates sharp peaks in the distributions and average compositions that are more FeO-poor than H, L or LL chondrites. The homogeneity of olivine (σ/mean) is 4.4%, which confirms classification as a type 4 chondrite (Sears and Hasan, 1987).

TABLE 1. Representative olivine and pyroxene compositions (in wt%) from Burnwell.

	Olivine							Pyroxene						
SiO_2	39.90	39.74	39.50	39.38	39.40	39.86	39.80	56.38	57.07	56.58	56.60	56.62	57.05	57.01
Al_2O_3	–	–	–	–	–	–	–	0.19	0.06	0.10	0.13	0.16	0.11	0.14
TiO2	–	–	–	–	–	–	–	0.15	0.08	0.08	0.12	0.11	0.10	0.10
FeO	14.80	15.50	14.80	14.72	14.70	14.92	14.50	9.27	8.77	8.76	8.85	9.52	9.18	9.37
MnO	0.54	0.50	0.47	0.50	0.44	0.47	0.44	–	–	–	–	–	–	–
MgO	44.96	45.11	44.77	44.67	44.77	44.77	44.78	32.86	33.81	33.20	33.64	33.24	33.65	33.50
CaO	–	–	–	–	–	–	–	0.29	0.22	0.83	0.30	0.32	0.34	0.30
Cr_2O_3	–	–	–	–	–	–	–	0.12	0.04	0.11	0.08	0.05	0.10	0.11
Total	100.20	100.85	99.54	99.27	99.31	100.02	99.52	99.26	100.06	99.66	99.72	100.02	100.54	100.52
Fa	*15.78*	*16.1*	*15.71*	*15.67*	*15.59*	*15.95*	*15.61*							
Fs								*13.73*	*12.53*	*13.09*	*12.63*	*13.65*	*13.12*	*13.43*

1σ errors on major elements are 0.02% or less.

Modal analysis of 1057 points on an area of USNM 6847-2 revealed 21.8 ± 4.1 wt% Fe,Ni metal and 4.6 ± 1.4 wt% FeS (errors represent 2σ uncertainties based on counting statistics). Thus, Burnwell may be richer in metallic Fe,Ni than H chondrites (Gomes and Keil, 1980) (Table 2). The average Co concentration in kamacite is 0.36 ± 0.04 wt% (1σ standard deviation, N = 25), outside the observed range of typical H chondrites.

The Burnwell meteorite is weakly shocked and shows evidence for possible brecciation. Shock melt veins and pockets are absent. The presence of planar fractures and undulatory extinction in olivine indicate shock stage S3. The meteorite contains a small number of dark clasts (six in a 35 cm^2 cut face). The largest such clast in USNM 6847-2 measures 0.9 × 2 mm in dimension. It contains a marked layering and numerous elongate metal and troilite particles. This structure is typical in shock-blackened meteorites and shock melt veins in ordinary chondrites. We suggest that these dark clasts were heavily shocked prior to their incorporation into the meteorite. The olivine composition of grains within the dark clasts is similar to the composition of olivine in chondrules, which suggests the clasts were incorporated before metamorphism.

TABLE 2. Summary of petrologic and isotopic data for classification of the Burnwell meteorite.

	Burnwell	Netschaëvo	H	L	LL
Petrologic Type	4	6			
Shock Stage	S3				
Olivine Fa*	15.8 ± 0.2	14.1	16.9–20.4	22.7–25.6	27.5–30.2
Low–Ca pyroxene Fs*	13.4 ± 0.7	13.6	15.7–18.1	18.7–22.6	23.2–25.7
Modal Fe,Ni†	21.8 ± 4.1	22.6	14.2–19.8	4.4–11.7	3.0–6.0
Modal FeS†	4.6 ± 1.4	5.9	3.6–7.2	3.8–6.7	4.0–6.9
Cobalt in kamacite†	0.36 ± 0.04	0.45	0.44–0.51	0.70–0.95	1.42–37.0
Chondrule diameter (μm)	360 ± 180	–	~300	~600–800	~900
$\Delta^{17}O$ (‰)	0.51 ± 0.02	0.57	0.73 ± 0.09	1.07 ± 0.09	1.26 ± 0.12

*units in mol%.
†units in wt%.
References: Netschaëvo data from Bunch *et al.* (1970) for mineral compositions; McCoy (1995) for modes; Rubin (1990) for Co in kamacite; and Clayton and Mayeda (1996) for O isotopic composition.
Data for H, L and LL chondrites from Keil and Fredriksson (1964) and Gomes and Keil (1980) for mafic silicate compositions and modal abundances of Fe,Ni and FeS; Rubin (1990) for Co concentrations in kamacite; Grossman *et al.* (1988) for chondrule diameters; and Clayton *et al.* (1991) for O isotope compositions.

Bulk Chemistry

Bulk wet chemical analyses were performed on a 2 g aliquot taken from a powdered 23 g sample of the Burnwell meteorite, using standard protocols at the Smithsonian Institution (Jarosewich, 1966, 1990). Results of the analyses are shown in Table 3. The meteorite has a chemical composition that most closely matches that of H group chondrites, although it is richer in metallic Fe and poorer in FeO than average H chondrites (Table 3, Fig. 3). Note that the Fe,Ni metal and FeS abundance acquired by the wet chemistry technique is somewhat lower than the values obtained by point counting. This can be accounted for by a sampling artifact of the point-counting technique. Normative mineralogies can be used as a classification indicator for ordinary chondrites (McSween *et al.*, 1991). Our data give normative abundances of 38 wt% olivine

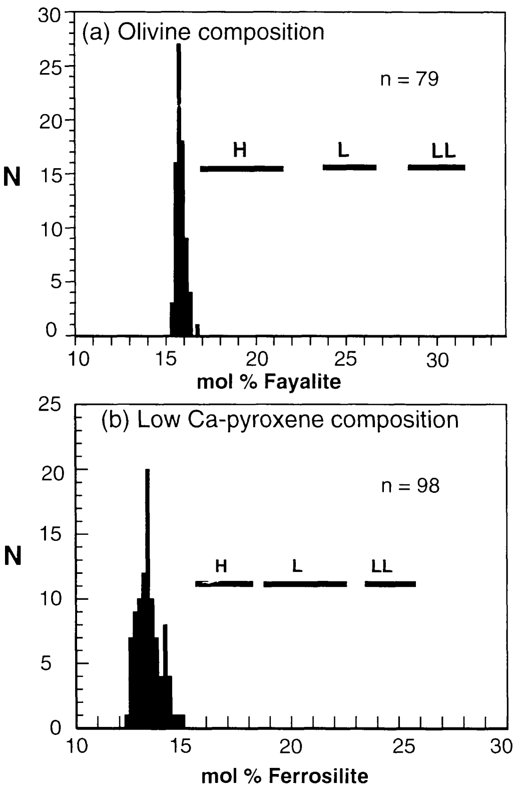

FIG. 2. Olivine (a) and low Ca-pyroxene (b) compositions for Burnwell. The sharp peaks in composition indicate Burnwell is equilibrated. Olivine and pyroxene in Burnwell are more FeO-poor than the same phases in H, L, and LL chondrites.

TABLE 3. Bulk composition of the Burnwell meteorite (in wt%) compared to data for average H, L and LL chondrite falls from Jarosewich (1990).

	Burnwell	H	L	LL
SiO_2	36.34	36.60	39.72	40.60
		0.55	*0.55*	*0.54*
TiO_2	0.10	0.12	0.12	0.13
		0.01	*0.01*	*0.02*
Al_2O_3	2.33	2.14	2.25	2.24
		0.15	*0.15*	*0.08*
Cr_2O_3	0.54	0.52	0.53	0.54
		0.03	*0.04*	*0.03*
FeO	9.43	10.30	14.46	17.39
		1.16	*1.07*	*2.06*
MnO	0.30	0.31	0.34	0.35
		0.02	*0.02*	*0.02*
MgO	23.80	23.26	24.73	25.22
		0.38	*0.41*	*0.44*
CaO	1.82	1.74	1.85	1.92
		0.09	*0.10*	*0.11*
Na_2O	0.70	0.86	0.95	0.95
		0.04	*0.05*	*0.06*
K_2O	0.09	0.09	0.11	0.10
		0.01	*0.01*	*0.02*
P_2O_5	0.29	0.27	0.22	0.22
		0.03	*0.04*	*0.04*
H_2O^+	0.20	0.32	0.37	0.51
		0.44	*0.45*	*0.55*
H_2O^-	0.16	0.12	0.09	0.20
		0.11	*0.07*	*0.14*
Fe (m)	17.87	15.98	7.03	2.44
		1.53	*0.95*	*1.61*
Ni	1.80	1.74	1.24	1.07
		0.09	*0.10*	*0.13*
Co	0.08	0.08	0.06	0.05
		0.02	*0.01*	*0.01*
FeS	3.64	5.43	5.76	5.79
		0.38	*0.80*	*1.04*
Total	99.49	99.99	99.99	99.92
Total Fe	27.51	27.45	21.93	19.63
		0.84	*0.80*	*0.68*

Italicized numbers are ±1σ of averages.

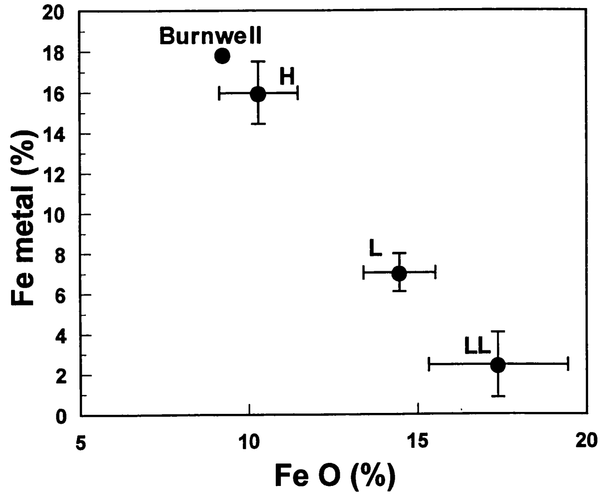

FIG. 3. Wet chemical analysis of FeO *vs*. Fe (metal) for Burnwell compared to average values for H, L, and LL falls (Jarosewich, 1990; bars indicate ±1σ). Burnwell has a higher metal content and lower FeO than most H chondrites.

and 25 wt% hypersthene, which is within the typical range for H chondrites.

Oxygen Isotopes

The O isotopes were measured using an online UV laser fluorination technique (Rumble *et al.*, 1998). Three separate analyses were conducted. Each analysis consisted of gas collected from four laser spots that were each 400 x 800 μm in size. The mean compositions were $\delta^{17}O = 3.61 \pm 0.02‰$; $\delta^{18}O = 5.97 \pm 0.02‰$; $\Delta^{17}O = +0.51 \pm 0.02‰$. The $\Delta^{17}O$ value lies at the lower limit of the range observed for H chondrites.

DISCUSSION

Classification

The Burnwell meteorite cannot be classified easily into the chemical groups of ordinary chondrites (H, L, LL). As we have shown, the Burnwell meteorite has lower Fa in olivine, Fs in orthopyroxene, Co in kamacite, FeO in the bulk chemical analysis, and $\Delta^{17}O$ than observed in equilibrated ordinary chondrites and higher Fe,Ni metal than observed in H chondrites. Figures 3 and 4 illustrate the properties of the Burnwell meteorite compared to equilibrated H, L and LL chondrites. Many of the properties of the Burnwell meteorite are consistent with the posited "HH" chondrites, and this meteorite is the first equilibrated fall of this type. However, we refrain from applying this moniker since it implies a genetic significance that may not be fully justified at this point. We use the term "low-FeO chondrite" to describe the Burnwell meteorite and as we show in the next section, several possibly related meteorites.

Origins and Comparison to Other Low iron oxide Chondrites

Many chemical properties of the Burnwell meteorite plot on extensions of the H-L-LL trends of ordinary chondrites towards more reducing compositions (Fig. 4). Several authors have previously described other meteorites that contain mafic silicates with lower FeO abundances than found in H chondrites (Wasson *et al.*, 1993; McCoy *et al.*, 1994 and references therein). These meteorites are Willaroy, Moorabie, Suwahib (Buwah), Cerro los Calvos and Wray (a). While all of these meteorites share the property of having unusually low Fa in olivine and/or Fs in pyroxene, each of these meteorites plot on extensions of H-L-LL trends for some, but not all, of the criteria shown on Fig. 4. Three of the previously described low-FeO chondrites are unequilibrated meteorites (Willaroy, Moorabie and Suwahib (Buwah)) and all are finds. Thus, many of the properties normally used for classification (*e.g.*, metal abundance, $\Delta^{17}O$) cannot be readily applied due to terrestrial weathering effects or chemical disequilibrium within the meteorites. For this reason, the Burnwell meteorite, as an equilibrated fall, is particularly important among this small number of meteorites.

Bild and Wasson (1977) first argued that chondrule-bearing clasts in Netschaëvo extended the H-L-LL trend. Netschaëvo contains FeO-poor silicates, abundant metal within the silicate clasts, low Co concentrations in kamacite and O isotopic compositions intermediate between H and E chondrites (Table 2 and references therein). However, questions have lingered about the possible reduction of Netschaëvo silicate clasts during their mixing with the metallic host and, thus, the exact nature of the silicate material prior to this mixing. Indeed, the Fa/Fs ratio of Netschaëvo is 1.04, which is below the ratio in equilibrated H chondrites (1.08–1.14; Keil and Fredriksson, 1964). Since diffusion occurs more quickly in olivine than in pyroxene, low Fa/Fs ratios indicate that reduction has affected Netschaëvo silicate inclusions. Wasson *et al.* (1993) argued

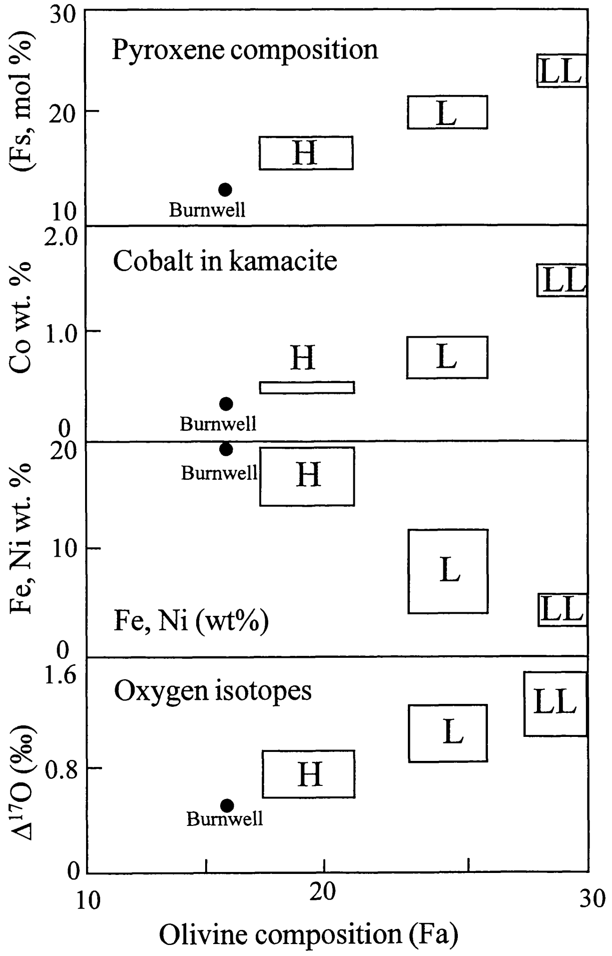

FIG. 4. Comparison of Burnwell to equilibrated H, L, and LL chondrite falls using established criteria for determining meteorite classification: (a) composition of low-Ca pyroxene; (b) abundance of cobalt in kamacite grains; (c) abundance of metal; and (d) O isotope composition. Data for Burnwell are shown by filled circles. Data for ferrosilite compositions and metal abundance of H, L and LL meteorites are from Gomes and Keil (1980). Data for cobalt in kamacite compositions are from Rubin (1990) and ordinary chondrite O isotopic compositions are from Clayton *et al.*, 1991.

that the low-FeO chondrites were originally normal H or L chondrites that have been reduced during metamorphism in a highly reducing regolith. However, the Fa/Fs ratio in the Burnwell meteorite is 1.18, which is similar to equilibrated ordinary chondrites. This suggests that reduction did not play a role in establishing its mineral compositions; and we have not located any likely reducing agent (*e.g.*, graphite) or evidence for fluid interaction within this meteorite. We find the correlation of properties that are not specifically a function of oxidation state (*e.g.*, $\Delta^{17}O$) with those that are indicative of oxidation state (*e.g.*, Fa in olivine) an unlikely result of reduction. Finally, reduction of a rock the size of the Burnwell meteorite in a reducing regolith would probably require a higher temperature of metamorphism than this meteorite has experienced.

The H-L-LL chondrite trend is generally attributed to incorporation of different proportions of nebular components between groups. We suggest that the low-FeO chondrite Burnwell attained its unusual chemical properties in the same fashion. The identification of such a distinct type of meteorite could have important implications for the number of meteorite parent bodies sampled in our collections. The ordinary chondrites are assumed to sample at least three distinct parent bodies (H, L, LL) and low-FeO chondrites may sample another parent body, as suggested by McCoy *et al.* (1994). However, the establishment of a new group and, thus, a new parent body will require both a larger number of members and evidence of a clear hiatus in properties between H and low-FeO chondrites. The examination of a large number of low fayalite H chondrites from the Antarctic meteorite collection could allow us potentially to determine if there is an extended H chondrite compositional continuum or two distinct meteorite groups. A comparison of the cosmic-ray exposure ages of H chondrites and low FeO chondrites also would be a helpful factor in determining whether they originated on the same parent body.

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