Studies of Brazilian Meteorites VII. Mineralogy, Petrology, and Chemistry of the Uberaba, Minas Gerais, Chondrite *

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(With 2 text-figures)

INTRODUCTION

The Uberaba, Minas Gerais, meteorite, also referred to as Dores dos Campos Formosos, fell at 10.00 a.m., local time on June 29, 1903, at Fazenda do Capão Grosso (approximate coordinates 19° 49′ S, 48° 47′ W), Dores dos Campos Formosos disctrict, about 84 km from the city of Uberaba. The fall was accompanied by light and sound phenomena and, according to witnesses, after the appearance of a luminous meteor which traveled from the NE to the SW, a stone of about 30-40 kg was seen to fall. However, Hussak (1904), who was the first to give a preliminary description of the meteorite and a detailed account of the field investigations, pointed out that a considerable portion of the stone was destroyed by local residents and that only about half of that amount remained.

The meteorite was also listed by Oliveira (1931), Vidal (1936), and Hey (1966). Mason (1963) provided data on the composition of its olivine as determined by X-ray diffraction and optical microscopy, and Van Schmus and Wood (1967), based on mineralogical and textural evidence, classified the stone as an H5 chondrite. As of this writing, however, no detailed study of this meteorite has been carried out. It is therefore the main purpose of the present paper to present a textural description of the meteorite, based on optical microscopy, as well as a compositional study of its constituent phases and of the bulk rock.

ANALYTICAL PROCEDURES

The texture of the meteorite was studied in transmitted and reflected light, and its constituent phases were analyzed with an electron microprobe. A bulk chemical analysis of the stone was made following the procedures described by Jarosewich (1966).

Electron microprobe analyses were carried out with an ARL EMX-SM instrument, using an accelerating potential of 15 KeV and a sample current of about 0.02 μAmp. The beam size was $\leqslant$ 1μm in diameter. Corrections were made for instrumental drift, background, and differential matrix effects, using the method of Bence and Albee (1968). Natural minerals of well-known composition (olivine Marjalahti; augite A-209; andesine AC-362; chromite C53IN8) were used as standards.

MINERALOGY AND PETROLOGY

The texture of the Uberaba stone is characterized by abundant, readily discernible chondrules, embedded into a fine-grainel matrix (Fig. 1A). The chondrules are perfectly round to alongate in shape and range in size from 0.2 — 1.1 mm (mean 0.5 mm). Their internal

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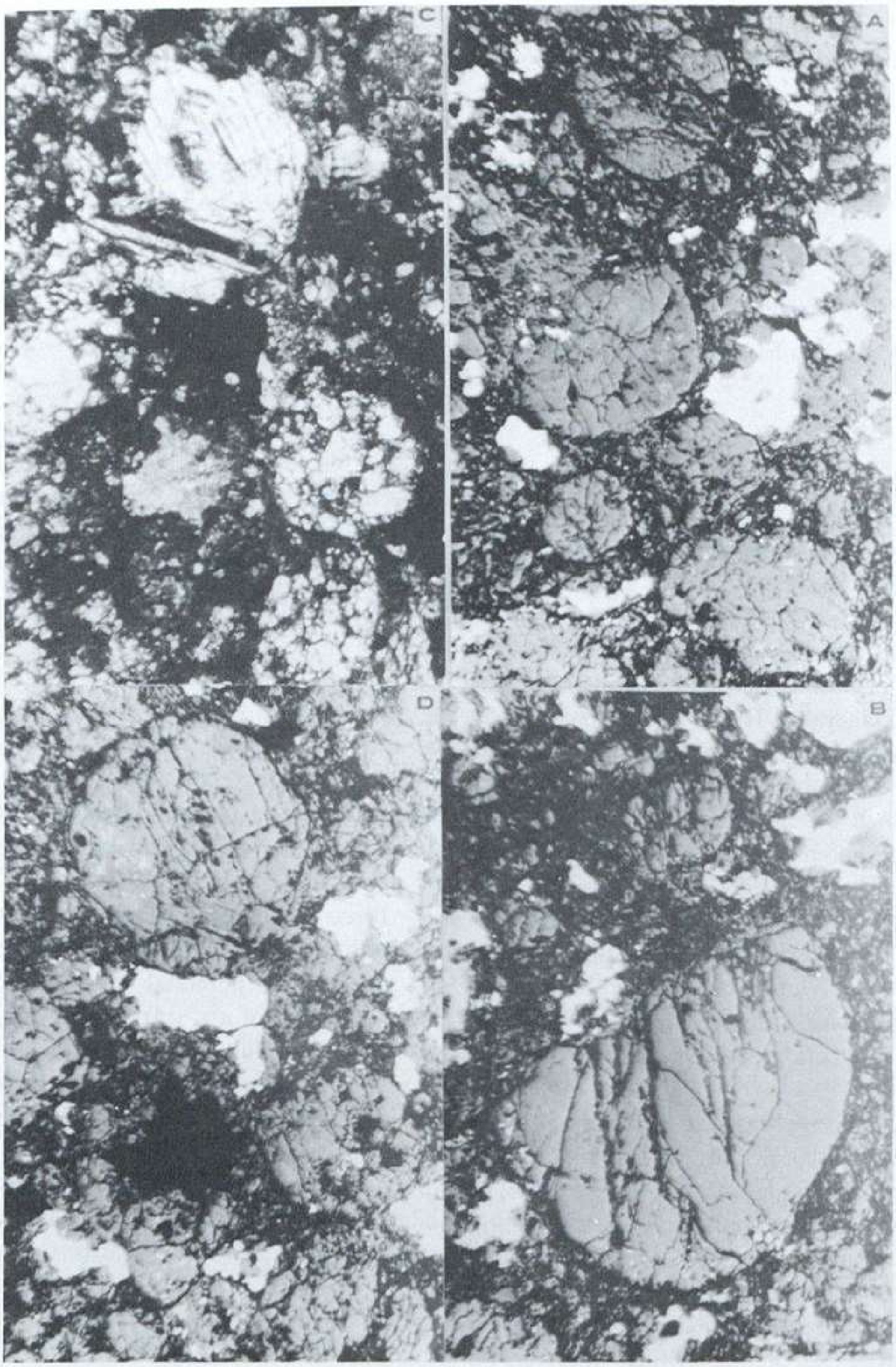

Fig. 1 A — Chondritic texture in the H5 meteorite Uberaba, Brazil. Metallic nickel-iron is white, whereas silicates (olivine, pyroxene) show different shades of gray. Reflected light. 50 ×. B — Relict chondrule of orthopyroxene. Cracks are black. Tiny grains, white color, are kamacite-taenite. Reflected light. 50 ×. C — Relict porphyritic chondrule (left, center) consisting mainly of olivine (large crystal, slightly zoned) and orthopyroxene (prismatic, twinned). White is metalic nickel-iron. Upper, right side, also a porphyritic chondrule. Transmitted light. 50 ×. D — Same as Fig. 1 C, but reflected light. 50 ×.

textures are variable, with polysomatic chondrules dominating over monosomatic ones. Porphyritic types are the most commom textural varieties, but barred, excentroradial, and granular chondrules were also observed (Figs. 1B-D).

OLIVINE: Olivine is the most abundant mineral in the meteorite. It occurs within chondrules and as grains in the matrix. Crystals are anhedral to euhedral and vary in size from about 10 - 1000 μm. In chondrules, olivine is usually associated with orthopyroxene. Olivines in chondrules and the matrix are identical in composition (average $Fa_{19.5}$; TABLE I) and are homogeneous (Fig. 2). Their compositon is well within the range of olivine from H-group chondrites (Fig. 2) (Keil and Fredriksson, 1964; as modified by Fodor *et al.*, 1976).

PYROXENE: Orthorhombic pyroxene (bronzite) occurs in chondrules and in the matrix, whereas high-Ca clinopyroxene was only observed in the matrix. The former is by far the most abundant, forming lamellar to prismatic crystals. High-Ca clinopyroxene (dipside) is generally found as granoblastic grains. Orthopyroxene ranges from <20-900 μm and, occasionally, larger individuals occur in a radiating texture or poikilitically enclose olivine. Clinopyroxene occasionally shows polysynthetic twinning. Orthopyroxene in chondrules and in the matrix is identical in composition (average $En_{81.6}$ $Fs_{17.1}$ $Wo_{1.3}$; Table I) and is homogeneous from grain to grain (Fig. 2). Its composition is within the compositional range for H-group chondrites (Fig. 2) (Keil and Fredriksson, 1964; as modified by Fodor *et al.*, 1976).

KAMACITE, TAENITE, AND TROILITE: Metallic nickel iron (kamacite and taenite) is a major mineral in this meteorite. The bulk chemical analysis indicates at least 15.28% metal; microscopy indicates that kamacite is far more abundant than taenite. Metallic nickel-iron grains are irregular in shape, ranging up to about 1,100 μm in longest dimension. Most of the metal is in the matrix of the meteorite, and the chondrules usually have low amounts of the phase. The metal, in many places, has

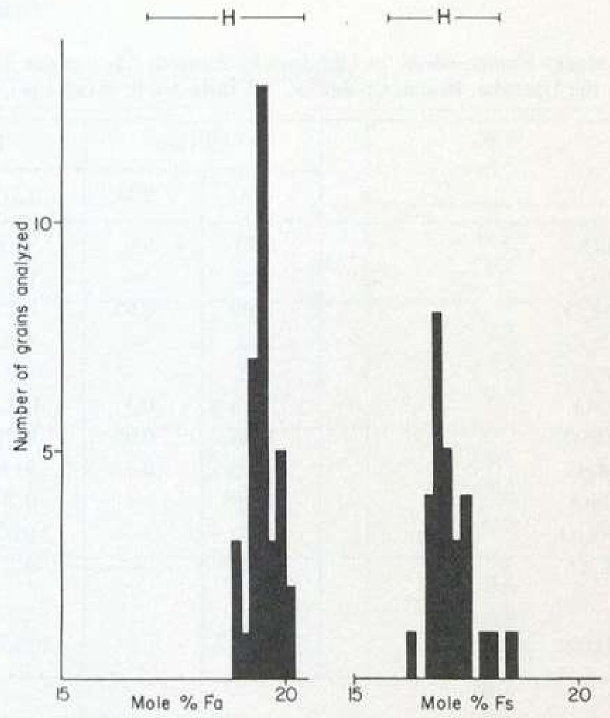

Fig. 2 — Histograms illustrating the compositions of olivine (Fa; $FeSiO_4$) and orthopyroxene (Fs: $FeSiO_3$) in the Uberaba chondrite. For comparison the ranges for the H-group chondrites are given (Keil and Fredriksson, 1964; as revised by Fodor *et al.*, 1976).

rims of terrestrial hydrous ferric oxide. Troilite occurs as anhedral, irregular grains up to about 500 μm in size and is usually associated with metallic nickel-iron.

PLAGIOCLASE: This mineral was found as small, granoblastic grains in the matrix of the meteorite. It is uniform and homogeneous in composition (average $Or_{4.8}$ $Ab_{83.9}$ $An_{11.3}$) and is typical for plagioclase from H-group chondrites (Van Schmus and Ribbe, 1968).

CHROMITE: This phase occurs in accessory amounts and in small, often fractured grains, ranging in size up to about 200 μm. It is homogeneous in composition (TABLE I) and within the range for chromite from H-group chondrites given by Bunch *et al.* (1967).

BULK CHEMICAL COMPOSITION

The bulk chemical analysis of Uberaba and the CIPW molecular norm are presented in TABLE II. The analysis indicates that the meteorite belongs to the H-group. Specifically, H-group (Keil, 1969) classification is apparent

TABLE I

Average Compositions, as Obtained by Electron Microprobe Techniques, of Olivine, Bronzite, Plagioclase, and Chromite from the Uberaba, Brazil, Chondrite. All Data are in Weight per cent. Number of Grains Analyzed are Shown in Parentheses.

	Olivine		Bronzite		Plagioclase		Chromite	
	(34)	S.D.	(28)	S.D.	(6)	S.D.	(19)	S.D.
SiO_2	39.1	0.9	56.6	0.5	65.0	0.6	0.10	0.02
TiO_2	n.d.	—	n.d.	—	n.d.	—	2.4	0.2
Al_2O_3	0.09	0.03	0.25	0.08	21.3	0.2	6.2	0.2
Cr_2O_3	n.d.	—	n.d.	—	n.d.	—	55.7	0.6
V_2O_3	n.d.	—	n.d.	—	n.d.	—	0.69	0.03
FeO	18.3	0.3	11.6	0.4	0.88	0.16	30.5	0.7
MnO	0.48	0.03	0.48	0.03	n.d.	—	1.09	0.09
MgO	42.5	0.4	31.0	0.3	0.42	0.06	3.4	0.4
CaO	<0.01	—	0.70	0.12	2.4	0.3	n.d.	—
Na_2O	n.d.	—	0.07	0.04	10.0	0.3	n.d.	—
K_2O	n.d.	—	n.d.	—	0.86	0.14	n.d.	—
Total	100.47		100.70		100.86		100.08	

Number of Ions on the Basis of

	0 = 4		0 = 6		0 = 32		0 = 32	
Si		0.994		1.989		11.436		0.028
Ti		—		—		—		0.504
Al		0.003		0.010		4.416		2.067
Cr		—		—		—		12.459
V		—		—		—		0.157
Fe		0.389		0.341		0.129		7.216
Mn		0.010		0.014		—		0.261
Mg		1.610		1.623		0.110		1.434
Ca		0.000		0.026		0.462		—
Na		—		0.005		3.411		—
K		—		—		0.193		—
Z		0.994		1.999		15.852	SUM^{+3}	15.215
X		2.012		2.009		4.305	SUM^{+2}	8.911
SUM		3.006		4.008		20.157		24.126
	Fo	80.5	En	81.6	Or	4.8	Uv	6.4
	Fa	19.5	Fs	17.1	Ab	83.9	Cm	77.2
			Wo	1.3	An	11.3	Pcm	3.8
							Sp	12.6

S.D. — Standard deviation; n.d. — not determined

from the ratios of Fe^o/Ni^o of 7.80 (average H-group 10.90; Craig, 1964); Fe^o/Fe_{total} of 0.52 (average H-group 0.63; Van Schmus and Wood, 1967); and Fe_{total}/SiO_2 of 0.70 (average H-group 0.77; Van Schmus and Wood, 1967). It should be noted that the Fe^o/Fe_{total} is slightly low, due to terrestrial weathering of metalic nickel-iron to hydrous ferric oxide, thus yielding slightly low Fe^o. H-group classification is further evident on the basis of Fe_{total} of 26.08% (average H-group 27.52%; Craig, 1964) and of the total metallic nickel-iron content of 15.28% (average H-group 16.72%; Keil, 1962 a, b). Although the total metallic nickel-iron value is well within the range for H-group chondrites (14.17 — 19.81%; Keil, 1962 a, b), it is slightly on the low side due to terrestrial weathering of metallic nickel-iron.

TABLE II

Chemical Analysis and CIPW Molecular Norm of the Uberaba Meteorite

SiO_2	37.50	Olivine	Fo	26.8
TiO_2	0.12		Fa	10.7
Al_2O_3	2.30	Hypersthene	En	18.7
Cr_2O_3	0.55		Fs	6.8
FeO	11.52		Wo	2.2
MnO	0.32	Diopside	En	1.5
MgO	23.43		Fs	0.5
CaO	1.78		Ab	7.6
Na_2O	0.90	Plagioclase	An	2.0
K_2O	0.09		Or	0.5
P_2O_5	0.25	Apatite		0.6
H_2O^+	0.57	Chromite		0.8
H_2O^-	0.05	Ilmenite		0.2
Fe	13.50	Nickel-iron		15.3
Ni	1.73	Troilite		5.7
Co	0.05			
FeS	5.70			
Total	100.36*			
Total Fe	26.08			

* NOTE: This sample also contains 0.09% carbon.

CONCLUSIONS

On the basis of mineral compositions, particularly olivine ($Fa_{19.5}$), orthopyroxene ($Fs_{17.1}$), and chromite it is concluded that the Uberaba chondrite belongs to the H-group. This conclusion is further supported by the results of the bulk chemical analysis, particularly the ratios Fe^o/Ni^o (7.80), Fe^o/Fe_{total} (0.52), and Fe_{total}/SiO_2 (0.70), as well as the contents of Fe_{total} (26.08%) and metallic nickel-iron (15.28%). The well-developed chrondritic texture of the chondrite, the presence of interstitial plagioclase, and the uniform and homogeneous composition of olivine and orthopyroxene suggest that Uberaba belongs to the petrologic class H5 of Van Schmus and Wood (1967), in agreement with the earlier results by these authors.

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SUMMARY

A study of the Uberaba, Minas Gerais, Brazil, chondrite by optical microscopy, electron microprobe and bulk chemical techniques shows that this stone has a well-developed chondritic texture and consists of major amounts of olivine ($Fa_{19.5}$), orthopyroxene ($Fs_{17.1}$), metallic nickel-iron and troilite, minor amounts of plagioclase ($Or_{4.8}Ab_{83.9}An_{11.3}$) and accessory amounts of high-Ca clinopyroxene, chromite, whitlockite, and chlorapatite. Mineral and bulk chemical compositions, particularly the compositions of olivine, orthopiroxene and chromite, and the bulk ratios of Fe^o/Ni^o (7.80), Fe^o/Fe_{total} (0.52), Fe_{total}/SiO_2 (0.70), and the bulk contents of Fe_{total} (26.08%) and metallic nickel-iron (15.28%) indicate that the meteorite belongs to the H-group. Texture and homogeneity of the silicate minerals suggest a classification in the petrologic class H5.

RESUMO

O estudo microscópico e químico (microssonda eletrônica e análise química global) do meteorito Uberaba,

Minas Gerais, Brasil, aponta o seu caráter fortemente condrítico e uma mineralogia constituída essencialmente de olivina ($Fa_{19,5}$), ortopiroxênio ($Fs_{17,1}$), kamacita-taenita e troilita; subordinadamente, aparecem plagioclásio ($Or_{4,8}Ab_{83,9}An_{11,3}$) e clinopiroxênio cálcico, enquanto que cromita, whitlockita e cloroapatita ocorrem como acessórios. A química mineral e global, em particular a composição da olivina, ortopiroxênio e cromita e as razões Fe^o/Ni^o(7,80), Fe^o/Fe_{total} (0,52), Fe_{total}/SiO_2 (0,70), aliado aos valores de Fe_{total} (26,08%) e das fases metálicas ferro-níquel (15,28%), indicam que o meteorito pertence ao grupo H dos condritos. Evidências texturais e a homogeneidade química dos minerais silicáticos são sugestivas de sua classificação na classe petrológica H5.

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