The Buritizal meteorite: classification of a new Brazilian chondrite

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Abstract

On August 14, 1967, the reporter Saulo Gomes, working at TV Tupi, went to a small city in the State of São Paulo called Buritizal to investigate reports of a meteorite fall and write a newspaper report. He actually recovered three fragments of the meteorite at a small farm. In 2014, he donated one of the fragments to the Museu Nacional of the Universidade Federal do Rio de Janeiro (MN/UFRJ). We named this meteorite Buritizal and studied its petrology, geochemistry, magnetic properties and cathodoluminescence with the intent to determine the petrologic classification of the meteorite. In this manner, the Buritizal meteorite is classified as an ordinary chondrite LL 3.2 breccia (as indicated by lithic fragments). The meteorite consists of ~ 2% of metallic Fe,Ni and many well-defined chondrules with ~ 0.8 mm in average diameter. An ultramafic ferromagnesian mineralogy is predominant in the meteorite, represented by olivine, orthopyroxene, clinopyroxene, Fe-Ni alloy, troilite and glass. The total iron content was calculated as 20.88 wt%. Furthermore, the meteorite was classified as weathering grade W1 and shock stage S3. Buritizal is the 25th observed meteorite fall recovered in Brazil, of 70 meteorites known from Brazil. Thus, the study of the Buritizal meteorite is very important and relevant for the Brazilian scientific community.

Keywords: Buritizal meteorite; well-defined chondrules; ordinary chondrite breccia.

1. Introduction

The detailed study of chondrites and their chondrules enables a better understanding of the genesis of the primordial solids in the solar system and their chemical variations and initial dynamic conditions. Study of chondritic meteorites provides important information on the origin and evolution of the first solids that formed from the solar nebula ~4.56 Ga ago and on the formation and evolution of their asteroidal parent bodies. Thus, the study of the Buritizal meteorite is important, since so far only 70 meteorites of all classes have been recovered in Brazil and officially classified at The Meteoritical Society, of which 25 meteorites among them are confirmed falls, now including the Buritizal meteorite (Buritizal meteorite link at the Meteoritical Bulletin Database website: http://www.lpi.usra.edu/meteor/metbull.php?code=63209).

On August 14, 1967, the reporter Saulo Gomes, working at TV Tupi, went to a small city in the State of São Paulo called Buritizal to investigate a meteorite fall and write a newspaper report. He recovered three fragments of the meteorite at a small farm. In 2014, Saulo Gomes donated one of the fragments to the Museu Nacional of the Universidade Federal do Rio de Janeiro (MN/UFRJ). The meteorite was previously nominated Saulo Gomes meteorite by Zanardo *et al.* (2011), but in this work, the meteorite received a name based on the Nomenclature Committee of the Meteoritical Society regulation, being called Buritizal meteorite. Lastly, the main goal of this paper concerns the Buritizal meteorite classification through analytical methods like petrology, geochemistry, magnetic and cathodoluminescence techniques to classify the meteorite into its chemical and petrologic groups and to determine its weathering grade and shock classification.

2. Analytical methods

Sample

The meteorite fragment studied here weighs 40.7g, is ~ 4x3x2 cm³ in volume and has a density of 3.3 g/cm³. Two polished thin sections of ~30 µm (0.03 mm) thickness were prepared using a thin circular saw in order to avoid sample loss.

Optical Microscopy

The polished thin sections were studied at the Laboratório de Microssonda Eletrônica (Labsonda), DEGEO UFRJ, using a binocular optical microscope Axioplan-Zeiss in transmitted plane and polarized light, as well as in reflected light, to determine the texture and mineralogy of the rock [e.g., Cohen & Hewins (2004), Huss *et al.* (2006), Norton & Chitwood (2008), Zucolotto *et al.* (2013), Scott & Krot (2014)]. Likewise, weathering grade (Wlotzka, 1993) and shock stage (Stöffler *et al.*, 1991) were determined, as well as abundances and types of chondrules (Gooding & Keil, 1981; Norton & Chitwood, 2008).

Electron Microprobe

The constituent minerals of the meteorite were analyzed in two polished thin sections using a JEOL electron microprobe JXA-8230, with five spectrometers, using an AxiomCam HRC – AX 10 camera and Zen2 Core software at the *LABSONDA, UFRJ*. The analyses were performed with a beam of 15 or 20 KV accelerating voltage, a 20 nA beam current.Reference standards of well-known compositions were used for quantitative analyses of all minerals of interest.

A total of 162 spots previously chosen by optical microscope were analyzed of minerals in chondrules, in the matrix and of metallic Fe,Ni. In the latter, the elements P, Fe, Cr, Ni, S, Co, and Si were determined, whereas Na_2O, Al_2O_3, SiO_2, MgO, FeO, CaO, TiO_2, $Cr2O_3$, NiO, and MnO were the major oxides determined in silicates of chondrules and matrix. Standard deviation statistical analysis for Ni content of troilite, Ni heterogeneity of kamacite (Sears & Dodd, 1988; Weisberg *et al.*, 2006), olivine (fayalite-forsterite), pyroxene (enstatite-ferrosilite), and also a standard deviation vs. the mean of Cr_2O_3 content (Grossman & Brearley, 2005) were performed. Comparison to literature data used to classify the Buritizal meteorite [e.g., Van Schmus & Wood (1967), Weisberg *et al.* (2006), Huss *et al.* (2006), Krot *et al.* (2014), Scott & Krot (2014)].

Magnetic susceptibility

The magnetic analyses were carried out at the *Centre de Recherche et d'Enseignement de Géosciences de l'Environnement - CEREGE*, France. The methodology is based on Rochette *et al.* (2003), in which systematic and non-destructive analyses can be done without loss of paleomagnetic signal of the meteorite. A magnetic field is induced in the sample, and then a magnetic answer (log X, with X in $10^{-9} m^3 kg^{-1}$) is measured proportionally to the bulk metal content of the sample. This analysis is a strong indicator of the chemical group of ordinary chondrites (H, L, or LL) (Weisberg *et al.*, 2006; Scott & Krot, 2014).

Cathodoluminescence

The cathodoluminescences analyses were carried out at the *Centro de Tecnologia Mineral (CETEM - UFRJ)* using a CITL model MK5-2 equipment with an Axio Imager M2m microscope and a Zeiss Zen Blue software. The analytical conditions were 15 KV accelerating voltage, beam current of 400uA (microampere) and exposure time of 4 seconds. Thereafter, the final selected 130 images were compiled with Gimp 2.8 software. The results obtained of the thin section were interpreted according to the methods proposed by Sears *et al.* (1990), Huss *et al.* (2006) and Krot *et al.* (2014), in which the cathodoluminescence colors (yellow, blue and red) are observed in chondrules mesostasis, matrix and olivine chondrules. The aim of these qualitative analyses are to classify the Buritizal meteorite in accordance to its petrologic subtype (Huss *et al.*, 2006).

3. Classification methods

In the classification methods summarized, for example, by Weisberg *et al.* (2006), the petrologic types 1 and 2 represent the carbonaceous chondrites that suffered aqueous alteration at temperatures below 400°C. The types 4, 5, 6 and 7 correspond to chondrites metamorphosed at higher temperatures. The petrologic type 3 corresponds to chondrites without considerable metamorphic alteration, that is, chondrites which have mineralogy, chemical composition and primitive texture similar to the first parental rocks formed in the solar system. In addition, Huss *et al.* (2006), summarize a robust synthesis on previous methods of chondrite petrologic classification, based on the work of Van Schmus & Wood (1967), Sears *et al.* (1990) and Sears & Dodd (1988), which subdivide type 3 ordinary chondrites into subtypes, ranging from 3.0 to 3.9.

4. Results

The Buritizal meteorite is largely covered by a dull to opaque, black fusion crust of ~ 1 mm thickness. The rock has a pronounced chondritic texture, with abundant well-defined chondrules of ~0.8 mm average diameter, together with ferromagnesian silicates and rock fragments (Figures 2b, 2c, 2d). Chondrules and fragments are embedded into a gray to black, fine-grained matrix (Figures 2c, 2e). The lithic clast in Figure 2c has a predominant beige brownish matrix with fine-grained aluminosilicates, cryptocrystalline material, mineral fragments and glass.

The meteorite is weakly shocked (S3), as indicated by planar and irregular well-defined fractures and by wavy extinction in olivine and orthopyroxene (Figure 2d), indicating a 15 – 20 GPa shock pressure, on the basis of the shock classification proposed by Stöffler *et al.* (1991).

The petrographic modal analyses indicates 83 vol.% of chondrules, 15 vol.% of matrix and 2 vol.% of metals, and forsterite, enstatite and clinoenstatite are the main minerals in the chondrules (Figures 2a, 2b, 2d). Microprobe results (Figure 1) indicate olivine compositions varying between $Fa_{0.2}$ to $Fa_{43.0}$ (n=28) and low Ca pyroxene between $Fs_{3.7}$ to $Fs_{33.9}$ and $Wo_{0.3}$ to $Wo_{9.5}$ (n=10).

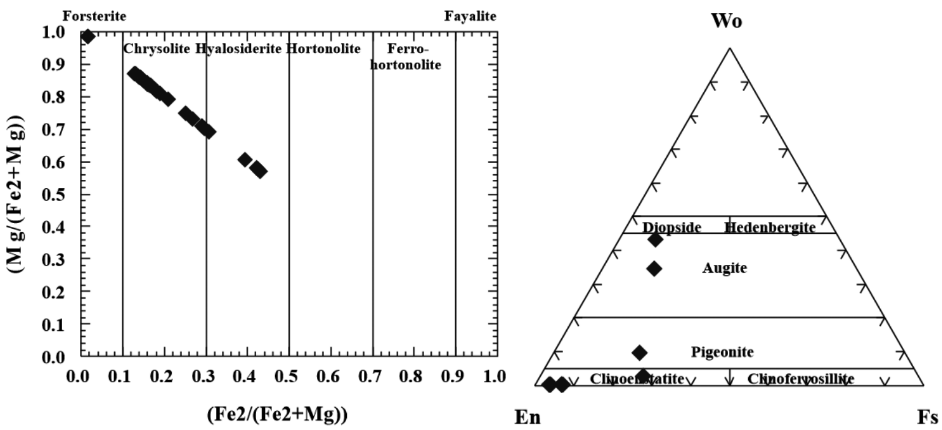

Figure 1
Compositional microprobe results of Olivine (Forsterite-Fayalite) at 28 collected points and Pyroxene (Enstatite-Ferrosilite--Wollastonite) at 10 collected points of Buritizal meteorite chondrules.

A textural chondrule classification system was done according to Lauretta *et al.* (2005). On that, porphyritic, non-porphyritic, granular and metallic chondrules are divided into 4 groups (1 to 4 respectively). The eight main petrographic types of chondrules (Gooding & Keil, 1981) are present and well detected at Buritizal meteorite. Therefore, according to that classification, the Buritizal meteorite has the following chondrule distribution: Group 1 – 46 vol.% of porphyritic olivine-pyroxene, 18 vol.% of porphyritic olivine and 13 vol.% of porphyritic pyroxene; Group 2 – 9 vol.% of radial pyroxene, 4 vol.% of barred olivine and 3 vol.% of cryptocrystalline chondrules; Group 3 – 6 vol.% of granular olivine-pyroxene; metallic chondrules < 1 vol.%.

The metallic chondrules are wrapped by troilite and composed of kamacite. Usually the kamacite has tetrataenite or taenite inclusions. Metallic Fe,Ni (Table 1; Figure 2e) consists of kamacite (93 wt% Fe), tetrataenite (48 wt% Fe), taenite (62 wt% Fe) and troilite (62 wt% Fe; 35 wt% S).

Table 1
Average chemical compositions of metallic Fe,Ni and troilite (in wt%). (bd = below detection).

Minerals	P	Fe	Cr	Ni	S	Co	Si	Total
Kamacite	0.03	92.95	0.08	4.55	0.70	1.29	bd	99.60
Tetrataenite	bd	47.59	bd	52.59	0.02	0.34	bd	100.54
Taenite	-	62.47	0.01	37.31	bd	0.66	0.01	100.46
Troilite	bd	61.76	0.02	0.08	35.04	0.13	0.20	97.23

Several chondrules are Al-rich, however, one of them is a chondrule consisting of a dust-laden shell presenting well-rounded rims of glass and Al-rich minerals that trap a gray dusty matrix at the center. The observed rims of the dust-laden shell (Figure 2f) have the following average composition obtained by microprobe analyses: 63.7 wt% SiO_2; 21.1wt% Al_2O_3; 6.7 wt% MgO; 4.1 wt% FeO; 3.3 wt% CaO; 0.6 wt% TiO_2; 0.4 wt% Cr_2O_3; 0.4 wt% Na_2O.

The chondrite LL group classification is based on the bulk density (3.3 g/cm^3), chondrule mean apparent diameter (0.8 mm), content of metallic Fe,Ni (2 vol%; Figure 2e), Co content of kamacite (1.3 wt%) (Weisberg *et al.*, 2006; Scott & Krot, 2014), total iron content (20.88wt%) (Van Schmus & Wood, 1967; Zanardo *et al.*, 2011; Zucolotto *et al.*, 2013). In addition, the Buritizal LL group classification is also based on a low magnetic susceptibility, indicated by log X = 4.47, that according to Rochette *et al.* (2003) belongs to the magnetic range of LL3 falls (logX = 4.37 ±0.24) associated with W1 low weathering grade of the meteorite (Wlotzka, 1993; Krot *et al.*, 2014).

The petrologic type 3.2 classification is based on several properties of the meteorite: 1. Standard deviation (~0.18) vs. mean of Cr_2O_3 content (~0.20 wt%)

in olivines, observed through a highly heterogeneity of Cr_2O_3 content (Huss *et al*., 2006; Grossman & Brearley, 2005); 2. Crystals of olivine PMD = 41.8 and pyroxene PMD = 61.2 (percent mean deviation), calculated through fayalite and ferrosilite compositions, respectively (Huss *et al*., 2006); 3. High chemical and textural heterogeneity that is typical of petrologic non-equilibrated chondrites; 4. Absence of albite in mesostasis chondrules of types I and II (Huss *et al*., 2006; Weisberg *et al*., 2006 – Items 3 and 4); 5. Matrix texture with less than 20% of recrystallization (Figure 2e). 6. Ni content of troilite (0.09wt%); 7. Heterogeneity of kamacite in Ni content (16.2wt%; Figure 2e) (Sears & Dodd, 1988; Weisberg *et al*., 2006 – Items 5, 6 and 7); 8. Cathodoluminescence (CL) (Figure 3) showing rare yellow CL, common blue CL in chondrule mesostasis, the presence of red CL in olivine chondrules and low matrix CL (Sears *et al*., 1990; Huss *et al*., 2006; Krot *et al*., 2014).

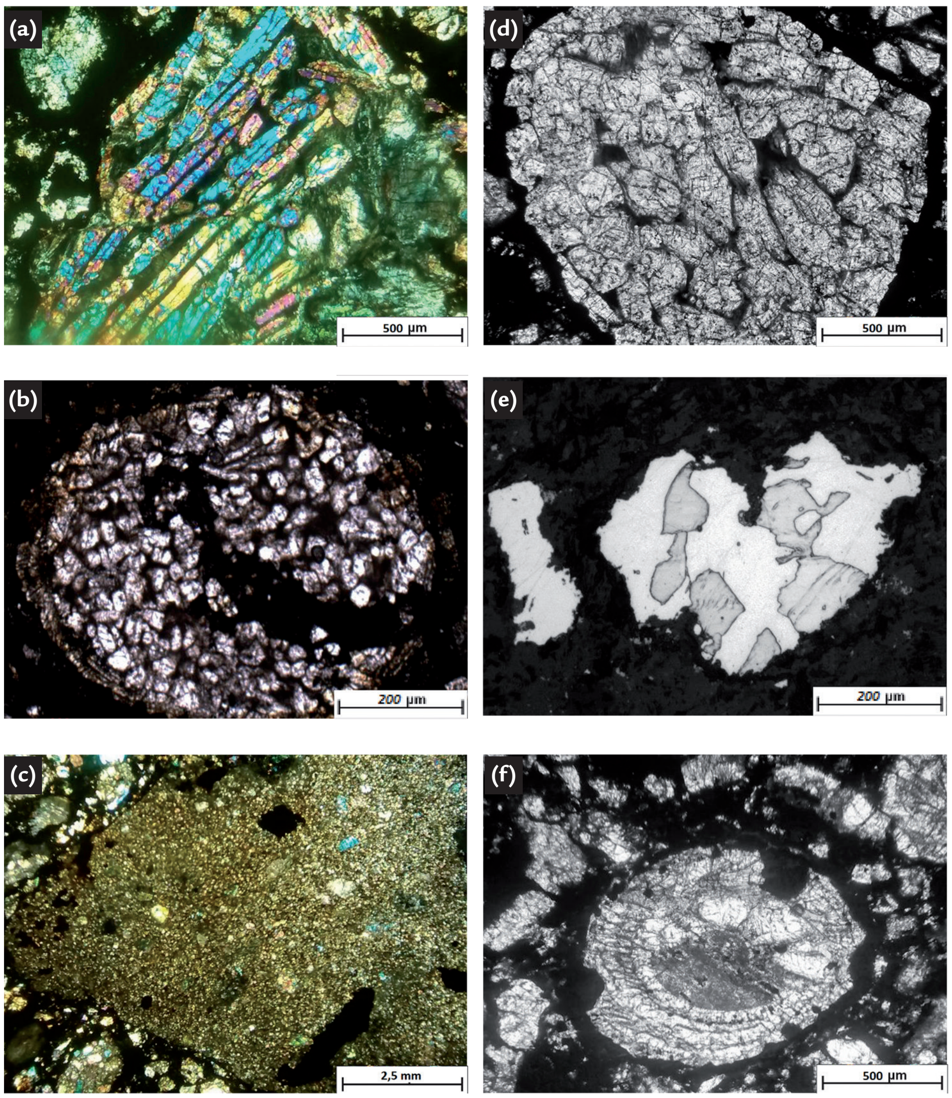

Figure 2
a) Barred olivine chondrule with sparse bars. b) Well delineated rounded granular olivine-pyroxene chondrule presenting troilite oxidation at the edge, surrounding the chondrule. c) Lithic clast with beige brownish matrix and cryptocrystalline fragments of glass, metals and aluminosilicates. (Photomicrographs obtained by transmitted crossed polarized light). d) Well defined porphyritic orthopyroxene chondrule presenting several typical planar and irregular fractures of S3 shock stage. e) Fe-Ni alloys kamacite (white) and taenite (beige), bordered by an opaque gray brownish matrix with low recrystallization. f) Dust-laden shell chondrule with well-rounded rims of aluminosilicates. (Photomicrographs obtained by transmitted plane polarized light, except 1E obtained by reflected light).

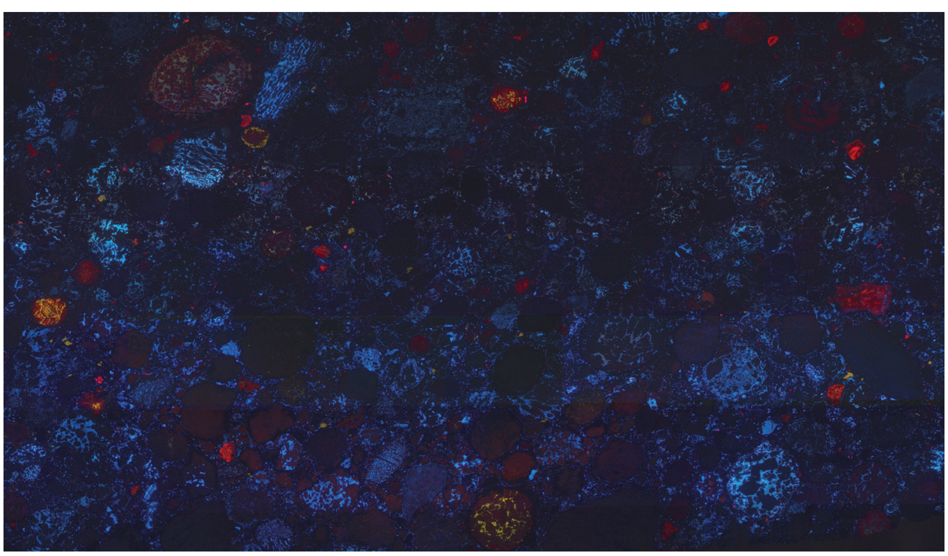

Figure 3
Compilation of 130 images obtained by cathodoluminescence (CL) analysis of Buritizal meteorite. Notice the common presence of blue CL and rare yellow CL in chondrule mesostasis, the presence of red CL in olivine chondrules and low CL in the matrix, indicating the petrological subtypes 3.2 to 3.4 (e.g., Huss *et al*., 2006).

5. Discussion

The Buritizal meteorite presents a well-developed chondritic texture with chemical composition and mineralogy consistent with a highly unequilibrated ordinary chondrite (e.g., Weisberg *et al*., 2006) as mentioned by the petrologic description of this work (see Figure 1 and Figure 3). Also, the presence of metallic chondrules suggests that, in some chondrites, these iron metals were formed by direct condensation from the solar nebula (Krot *et al*., 2000; Cohen & Hewis, 2004).

The concentric chondrule of dust-rims (Figure 2f) observed in the Buritizal meteorite has a particular texture that allow to unravel the possible genetic processes involved in its formation. According to Rubin (2013), concentric chondrules are formed when the cosmic dust is trapped and surrounded by silicates and glass during the first chondrule's formation stages in the earlier Solar System. According to Ciesla (2005), the concentric chondrules of dust-rims would be formed before the meteorite parental body formation. Therefore, zones containing Al-rich and concentric chondrules are mapped around the Sun showing a peak of dust zone formation around 3.6 Astronomical Units (AU). In turn, ordinary chondrites, which are the case of the Buritizal meteorite, corresponds to regions of formation that are 2-3 AU distant from the Sun (Rubin, 2013).

As pointed out above, the Buritizal meteorite has suffered a S3 shock stage (Figure 2d) on the scale developed by Stöffler *et al.* (1991). However, the presence of lithic clasts (Figure 2c) indicates that the Buritizal meteorite was affected by a higher shock stage (e.g., S6) and it is a breccia (Scott & Krot, 2014). The precisely type of the breccia and his components (Scott & Krot, 2014) was not conclusive. Despite that, the study indicates that Buritizal meteorite is a primitive accretionary breccia, that is, when their constituents (including clasts) are assembled during accretion stages of the Solar System.

6. Conclusions

Detailed mineralogic, petrologic, chemical, magnetic and cathodoluminescence studies show that the Buritizal meteorite, from Brazil, is an unequilibrated ordinary chondrite that presents a S3 shock stage and a W1 weathering grade. The occurrence of lithic clasts in the meteorite indicates that the meteorite is a breccia. This new Brazilian fall meteorite is approved and listed as the 70th Brazilian meteorite by the Meteoritical Bulletin Database of The Meteoritical Society, as well as the Buritizal is officially named and classified as an Ordinary Chondrite LL3.2. Lastly, the Buritizal meteorite is the 20th LL3.2 meteorite officially classified in the World, which shows that the petrologic type 3.2 is rare in the World's meteorite collections. Therefore, the study of these type of pristine chondrites, like the Buritizal meteorite, can help to reveal the processes involving the early Solar System formation, is of scientific relevance.

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