The Cali Meteorite: Luminescence of a recently fallen H/L ordinary chondrite

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Abstract. The Cali meteorite fall occurred on 6 July 2007 at 21h33m±1m UTC. Some specimens were recovered just after their fall so they are extremely fresh materials. Mineral analysis and bulk chemistry revealed that the measured abundances for most elements closely match the values recorded for other ordinary chondrites classified as H/L. We present here thermoluminescence studies of this recently fallen meteorite in order to get additional information on the radiation environment, and the thermal history of this meteorite. Such information is revealed to be complementary with the range of orbital elements deduced from eyewitness reports of the fireball.

Keywords: Meteorite, chondrite, thermoluminescence, fireball, meteoroid, orbit
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INTRODUCTION: THE FALL OF CALI METEORITE

The Cali meteorite fall occurred on 6 July 2007 at 21h33m±1m UTC. In a recent paper [1] we characterized this meteorite as a new H/L ordinary chondrite, and also studied the circumstances of this fall. In total, 10 meteorite samples with a total mass of 478 g were recovered around 3º24.3'N, 76º30.6'W [1]. Most of the specimens found were quickly identified as meteorites because they exhibited a prominent fusion crust covering part of their surface (Fig. 1). Two astronomical associations, the *Asociación de Astrónomos Aficionados de Cali (ASAFI)* and the *Escuela de Astronomía de Cali (EAC)* participated in the recovery. They also collected bolide reports in several municipalities of the Cauca Valley. Some eyewitnesses heard audible detonations a few minutes later of seeing the bolide. In the following minutes some meteorites penetrated the roofs of several houses on the outskirts of Cali. The interior of those pieces that broke during impact appear granular and dominated by large chondrules. Most of the large pieces were broken, but the small ones are completely fusion crusted. The meteorite appears to be brecciated.

The visual observations made of the daylight bolide from several locations around the Cauca Valley allowed the determination with moderate accuracy of the atmospheric trajectory, radiant, and range of orbital elements of the progenitor meteoroid [1]. Some assumptions of the bolide pre-atmospheric velocity suggest an origin in the main asteroid belt as in the case of the nine previous meteorites with known orbital elements [2]. Table 1 is a summary of the orbital results that were described in detail in [1]. Here we will focus in the luminescence properties of the meteorite that also give information on the thermal history of the progenitor meteoroid.

TABLE 1. Summary of presumable orbital elements (J2000.0) for the radiant and the range of possible pre-atmospheric velocities (12 to 18 km/s) given for the fireball [1].

a(AU)	e	q(AU)	Q(AU)	ω(°)	Ω(°)	i(°)
> 1	any	0.98 ±.02	>1	149±11	104.345±0.004	< 10

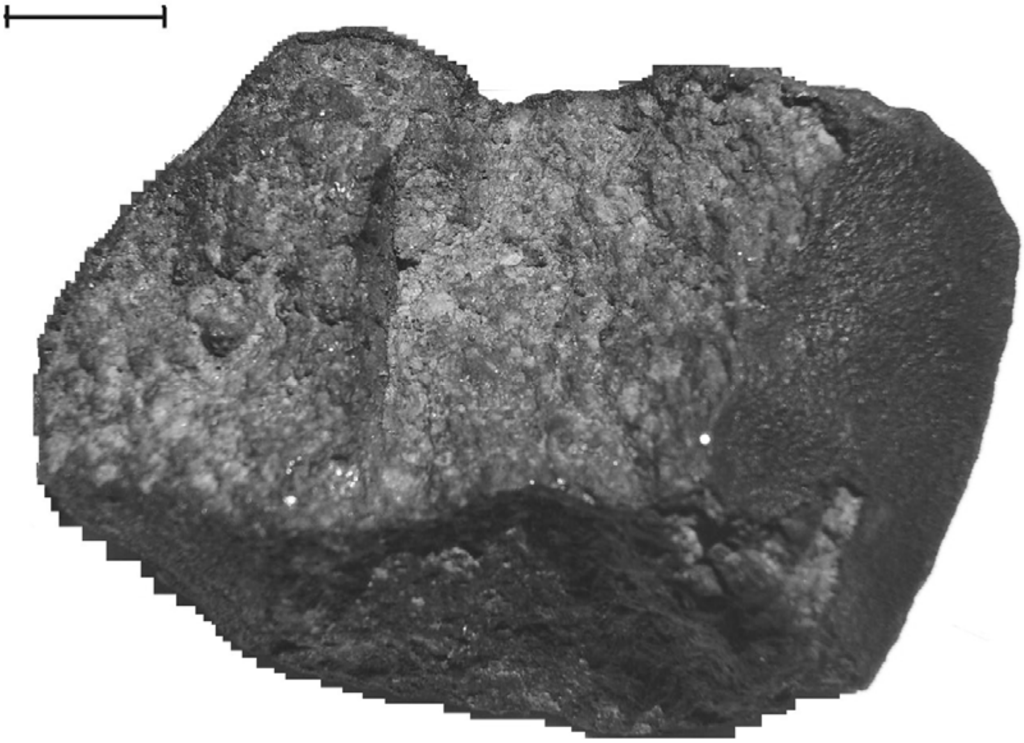

FIGURE 2. The first recovered meteorite by J. García was a 76.6 g piece that exhibits fusion crust over about 40% of the samples surface. The scale in the upper left corner is 1 cm.

SAMPLE PREPARATION METHODS

Natural and induced thermoluminescence properties were measured in two fragments of stone #6 using apparatus and techniques described in earlier publications (e.g., [3]). The bulk composition of Cali was determined on two samples from a ~1.2 g fragment of the interior of stone #6 by wet chemical methods [4]. Two independent methods were used for sample preparation, (1) an acid digestion treatment in a sealed

Teflon reactor; and (2) alkaline fusion in a zirconium crucible. Analyses were performed by means of inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma optical emission spectroscopy (ICP-OES).

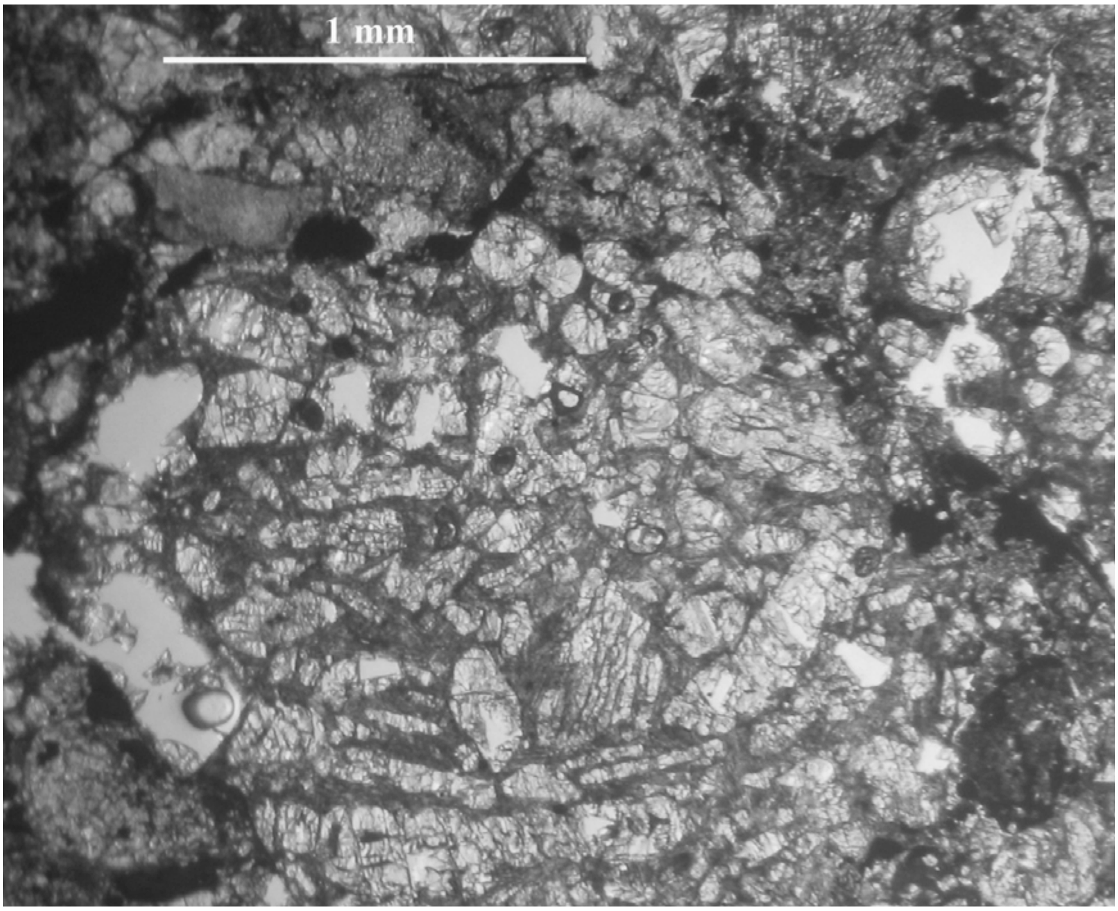

FIGURE 2. Transmitted optical microscope image of a porphiritic chondrule of Cali meteorite. The scale in the upper left corner is 1 mm.

RESULTS AND DISCUSSION

Bulk chemistry reveals that the measured abundances for most elements closely match the values recorded for other ordinary chondrites classified as H/L, including Bremervörde (H/L3.9) and Tieschitz (H/L3.6) [5].

We determined a natural TL value of 34±1 krad for Cali, consistent with an observed fall with a "normal" radiation and thermal history [3], i.e. similar to the ~95% of falls that have not been within 0.95 AU of the Sun (which would cause a factor of 10-100 lower natural TL, [6]) and have not recently (within the last 10^5 years) transferred to a near-Earth orbit (like the major ALH 85110 fall and its many paired fragments; [3]). These results are consistent with the orbit calculated above from eyewitness observations (Table 1).

TL can be also applied to characterize the petrologic type that allows an evaluation of the degree of metamorphism experienced by the chondritic parent bodies. Induced TL properties relate to the amount and nature of the major luminescence phosphor, which in ordinary chondrites (OCs) is feldspar. The TL sensitivity of a chondrite increases as feldespathic glass crystallizes as consequence of metamorphism. In unequilibrated OCs the feldespathic material is in form of a glass that is poorer phosphors than crystalline substances of similar composition because the TL mechanism involves lattice defects or impurity ions in the crystal lattice [7]. Consequently, the degree of TL is consequence of the metamorphic history and thus the petrologic type of the meteorite. Sears et al. [8] first showed that petrologic types 3, 4, 5 and 6 had TL sensitivity ranges of 0.002 to 1.0, 1.8 to 6.0, 6.0 to 14, and 6.0 to 25, respectively. While considerable work has been published on the type-3 ordinary chondrites, very little attention has been given to the higher types. It is important to remark that the TL method has allowed the identification of pristine (relatively unaltered) chondrites, but also a better characterization of the subgroups [9].

Based on existing data, our Cali induced TL measurements of 1.28 and 1.64, relative to Dhajala, suggest that this meteorite is either a very high type 3 (say 3.8 or 3.9) or petrologic type 4. The peak temperature and peak width, i.e. the temperature during readout at which induced TL intensity is at a maximum and the width of the peak at half-maximum, are 192±15 ^{o}C and 137±12 ^{o}C, for the first sample and 178±4 ^{o}C and 139±1 ^{o}C for the second sample, which would also be consistent with a high (greater than 3.5) petrologic type.

Other properties indicate that Cali is petrologic type 4 rather than high type 3. These include its moderate degree of recrystallization, the absence of igneous glass in most chondrules (and presence of turbid glass in a few chondrules), the occurrence of polysynthetically twinned low-Ca clinopyroxene phenocrysts in some porphyritic pyroxene (PP) and porphyritic olivine-pyroxene (POP) chondrules (Fig. 2), and relatively homogeneous olivine and heterogeneous low-Ca pyroxene compositions. On the other hand, the brecciated nature of this meteorite is well exemplified by the presence of fine-grained clasts all over the matrix (see e.g. Fig. 3). Using the criteria of Van Schmus and Wood [10], PMD_{FeO} for olivine is 4%, which is below the 5% minimum value defined for type 3 chondrites. This low value, coupled with the large scatter in pyroxene compositions (PMD_{FeO} for low-Ca pyroxene is 35%) is similar to observations from other type 4 chondrites [11], reflecting slower diffusion of Fe in pyroxene than in olivine during thermal metamorphism.

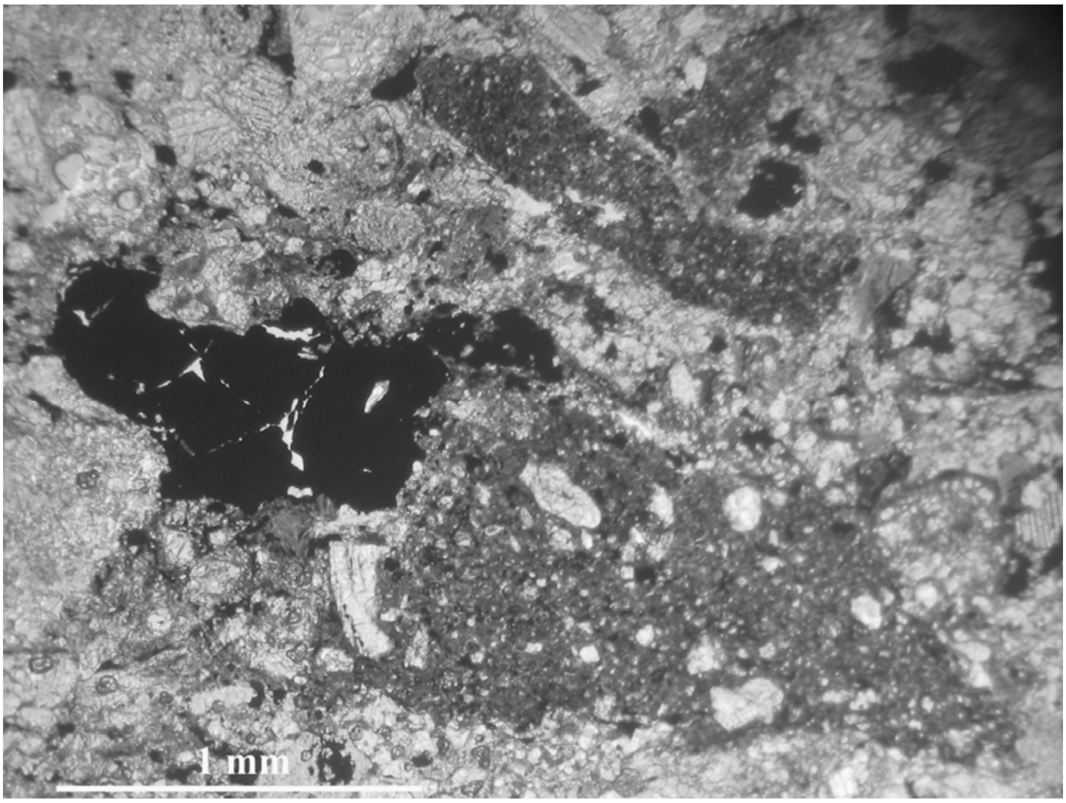

FIGURE 3. Transmitted optical microscope image of detached fine-grained clasts forming part of the matrix of this meteorite. The scale is 1 mm.

CONCLUSIONS

The Cali meteorite is an H/L4 ordinary chondrite breccia as established in [1]. Bulk chemistry revealed that the measured abundances for most elements closely match the values recorded for other ordinary chondrites classified as H/L. In the same way, mineralogical and physical properties are intermediate between H and L chondrites. Consequently, the Cali chondrite is an extremely interesting chondrite that deserves detailed studies to better understand its origin. With that goal we have performed a thermoluminescence analysis of this meteorite, and compared the results with the available dynamical information of the original meteoroid [1].

We found that the thermoluminescence measured value of 34 ± 1 krad is consistent with an observed fall with a "normal" radiation and thermal history. The fall was produced by a progenitor meteoroid that has not been within 0.95 AU of the Sun and has not recently (within the last 10^5 years) been transferred to a near-Earth orbit. These conclusions are consistent with the range of orbital elements calculated from eyewitness observations, which nicely exemplifies how the thermoluminescence technique provides valuable information on the radiation, and thermal histories of chondrites.

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