

Meteorite Fall at Sadiya, India: A Raman Spectroscopic Classification

Bhaskar J Saikia^{1*}, Parthasarathy G², Borah RR³, Borthakur R³ and Sarmah AJD⁴

¹Department of Physics, Anandaram Dhekial Phookan College, Nagaon, India

²National Geophysical Research Institute (CSIR-NGRI), Hyderabad, India

³Department of Physics, Nowgong College, Nagaon, India

⁴Department of Physics, Assam Downtown University, Guwahati, India

Abstract

This report demonstrates compositional, spectroscopic and mineralogical analysis of a new meteorite that fell at Natun Baliyan village of Sunpura, Sadiya, India on June 5, 2017. The olivine and pyroxene composition ($\text{Fe}_{28.97}$; $\text{Fe}_{0.103}$; $\text{Fs}_{24.47}$; $\text{En}_{74.03}$ and $\text{Wo}_{1.5}$) of the meteorite are determined. The measured Raman band positions are consistent with chemical composition for olivine and pyroxene. The compositional and spectroscopic analysis of the Sadiya meteorite sample show that the meteorite belongs to LL-5 type chondrite.

Keywords: Meteorite; Sadiya; Raman spectroscopy

Introduction

Meteorites are the only physical materials available on the Earth that allow direct study of the original dust from which the Solar System formed. The standard method for identifying meteorites is to compare the chemical composition of the sample with that of the meteoritic rock previously studied [1]. Classification of ordinary chondrite meteorites generally implies determining the chemical group by the composition in endmembers of olivine and pyroxene, and identifying the petrologic group by microstructural features [2]. Raman spectroscopy can be used as an alternative technique to determine the endmember content of olivine and pyroxene in ordinary chondrites. The distribution of Fe and Mg in olivine and pyroxene structures is reflected by the peak position in the Raman spectra because of the different size of the two ions, therefore providing a correlation between the obtained spectrum and the chemical composition [2].

We report here a recent meteorite fall that occurred on June 5, 2017 (04:30 pm IST) in Natun Baliyan village of Sunpura, Sadiya (27°50'09"N; 95°51'34"E). Generally, meteorites are named from their place of find or fall. Therefore, the recent fall meteorite studied here is named as Sadiya. According to the eye witness, a single stone was fallen in paddy field with a roaring sound and it formed an impact pit about 3.5 ft depth. The stone was fully covered with fusion crust and had well rounded edges and well developed regmaglypts on its surface (Figure 1). The weight of the meteorite was 3 kg and had specific gravity of about 3.4 g/cm³, typical of stony meteorites. A small part of the sample was taken for analysis and the main stone under custody of the district administration. The Sadiya meteorite fall represent the fifth 'observed fall' in North East India and it is the seventh meteorite of this region since 1846 [3]. This report demonstrates usefulness of Raman spectroscopic technique for classification of meteorite. The Raman spectroscopy could be used to analyze individual mineral grains in a completely non-destructive way, and it offers some unique capabilities as an analytical method in the study of the extent of the shock metamorphism in a chondrite, prior to the microscopical study [4]. Our preliminary compositional, spectroscopic and mineralogical analysis of the Sadiya meteorite sample show that the meteorite belongs to LL-5 type chondrite.

Methodology

Studies on bulk and mineralogical composition of meteorites provide very important constraint for testing theories of Solar System formation. As meteorites retain a record of the elements, and mineral

phases that existed in the system's accretionary stages. Microanalysis was performed using scanning electron microscopy (LEO 1430vp SEM) coupled with Oxford INCA energy dispersive X-ray spectrometer at accelerating voltage 20 kV and working distance 10 mm. A part of the sample was ground in an agate mortar and used for bulk chemical analysis of major and trace elements. The Raman spectra were collected on bulk powdered meteorite samples using an Ar ion laser with a power of ~5 mW, which used an excitation source having wavelength 488 nm coupled with a Jobin-Yvon Horiba LabRam-HR Micro-Raman spectrometer equipped with an Olympus microscope with 10X, 50X and 100X objectives, using the method described elsewhere [5,6].

Result and Discussion

The electron microscopic study of the meteorite sample reveals olivine, pyroxene and trillite as major minerals (Figure 2). All unweathered ordinary chondrites show these four iron-bearing minerals. Therefore, the presence of these minerals in Sadiya meteorite confirms that the meteorite under consideration is an LL-type ordinary chondrite



Figure 1: Photograph of Sadiya meteorite.

*Corresponding author: Bhaskar J Saikia, Department of Physics, Anandaram Dhekial Phookan College, Nagaon, India, Tel: +919678214200; E-mail: vaskaradp@gmail.com

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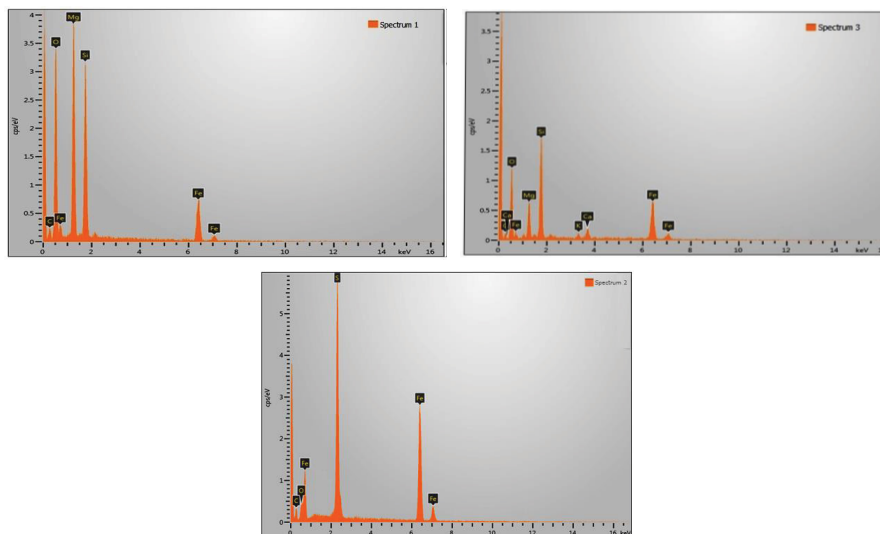


Figure 2: EDS spectra of minerals (Spectrum 1: Olivine; Spectrum 2: Pyroxene and Spectrum 3: Trolite of Sadiya meteorite.

Elements (wt%)	H	L	LL	CI	Sadiya
Si	16.9	18.5	18.9	10.5	18.4
Ti	0.06	0.063	0.062	0.042	0.23
Al	1.13	1.22	1.19	0.86	1.46
Cr	0.366	0.388	0.374	0.265	0.1
Fe	27.5	21.5	18.5	18.2	18.04
Mn	0.232	0.257	0.262	0.19	0.45
Mg	14	14.9	15.3	9.7	15.11
Ca	1.25	1.31	1.3	0.92	1.85
Na	0.64	0.7	0.7	0.49	0.83
K	0.078	0.083	0.079	0.056	0.68
P	0.108	0.095	0.085	0.102	nd
Ni	1.6	1.2	1.02	1.07	0.64
Co	0.081	0.059	0.049	0.051	nd
S	2	2.2	2.3	5.9	0.29
Atomic Ratios	H	L	LL	CI	Sadiya
Mg/Si	0.957	0.931	0.935	1.068	0.948
Al/Si(*10 ⁴)	696	686	655	853	826
Ca/Si(*10 ⁴)	518	496	482	614	705
Fe/Si(*10 ⁴)	8184	5845	4923	8717	4931
Ca/Al	0.74	0.72	0.74	0.72	0.85
Ni/Si(*10 ⁴)	453	310	258	488	166
CI Normalized Atomic Ratios	H	L	LL	CI	Sadiya
Mg/Si	0.9	0.87	0.88	1	0.889
Al/Si	0.82	0.81	0.77	1	0.968
Fe/Si	0.94	0.67	0.56	1	0.565

Table 1 Chemical composition and selected atomic ratios of Sadiya meteorite in relation to the composition and characteristic atomic ratios of ordinary chondrites groups and CI carbonaceous chondrites [8].

[6,7]. The results facilitated determination of the major elemental composition of Sadiya meteorite (Table 1), as well its comparison with the average values for H, L, LL and CI ordinary chondrites [8]. The range for chemical group in ordinary chondrite is generally expressed as endmember content. According to the definition in Van Schmus and Wood and in Hutchison [8,9], the chemical groups in ordinary chondrites are: H (Fa₁₆₋₂₀ and Fs₁₄₋₁₈), L (Fa₂₂₋₂₆ and Fs₁₉₋₂₂), and LL (Fa₂₇₋₃₂ and Fs₂₂₋₂₆). The olivine and pyroxene composition of Sadiya meteorite are estimated to Fa_{28.97}; Fo_{71.03}; Fs_{24.47}; En_{74.03} and Wo_{1.5}. These

values are identical to the LL group of ordinary chondrite. Chemical composition and selected atomic ratios of Sadiya meteorite are also represent LL group of ordinary chondrite (Table 1).

However, the Raman spectroscopy has not regularly been used as a method for meteorite chemical classification. This technique has already been used for meteorite characterization, especially Lunar and Martian rocks [10,11]. The correlation between composition of olivine and pyroxene has been investigated by many authors [11-14]. Recently, the potential of Raman spectroscopy has been largely exploited for the identification of shock-induced features or shock-induced polymorphs in meteorites and classification of the metamorphic stage in low-grade chondrites by many authors [4,15-17].

The Raman spectra of the sample shows (Figure 3) two characteristics peaks of olivine at 819.95 cm⁻¹ (Peak A); 850.20 cm⁻¹ (Peak B) and three characteristic peaks of pyroxene at 335.34 cm⁻¹ (Peak A); 678.49 cm⁻¹ (Peak B) and 1004.50 cm⁻¹ (Peak C) [5,6,18-20]. The endmembers are responsible for these characteristics peak changes [5,6,18-21]. Comparison of chemical group attribution based on theoretical Raman peak position prescribe by Pittarello et al. with the Raman peaks of Sadiya meteorite indicative to LL ordinary chondrite (Table 2) which is consistent to the compositional and mineralogical analysis.

Gyollai et al. indicates that the structural disordering in Si-O stretching vibrational modes and SiO₄ tetrahedra rotational vibrations are considerable to the shock-metamorphism [22]. The full width at half maximum (FWHM) of the peak is considered to be related to the degree of structural disorder of the crystal [4]. The FWHM values of Sadiya meteorite can be related to the degree of crystal structural disorder resulting from shock deformation. The measured FWHM averaged for the observed peaks for forsterites in the Sadiya meteorite sample is 10.42 cm⁻¹ for the component at 819.95 cm⁻¹ and 27.28 cm⁻¹ for the component at 850.20 cm⁻¹. The well-crystallized terrestrial olivines have FWHM value 9.1 cm⁻¹ and 9.5 cm⁻¹ corresponding to the peak positions at 820 cm⁻¹ and 854 cm⁻¹. The observed FWHM values of Sadiya meteorite are higher than those observed for well-crystallized terrestrial olivines. According to Miyamoto and Ohsumi [23], the FWHM value 10 cm⁻¹ for poorly shocked to 21 cm⁻¹ for strongly shocked meteorites. The FWHM value of ~10-27 cm⁻¹ in Sadiya meteorite in accordance with the moderate to strongly shocked stage [24]. The

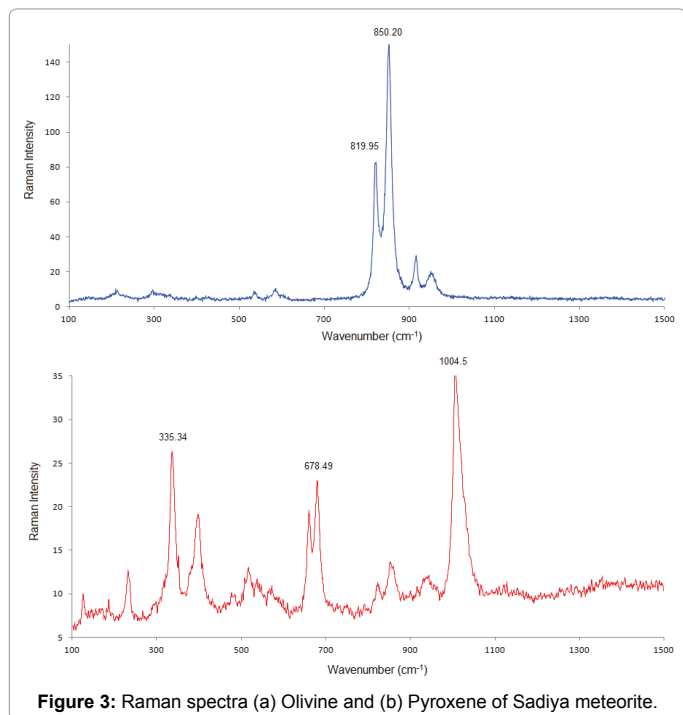


Figure 3: Raman spectra (a) Olivine and (b) Pyroxene of Sadiya meteorite.

Chemical Group	Peak A (cm ⁻¹)	Peak B (cm ⁻¹)	Peak C (cm ⁻¹)	
H	Fa ₁₆₋₂₀	821.9–822.3	852.5–853.4	--
	Fs ₁₄₋₁₈	337.9–339.5	681.2–682.5	1007.8–1009.0
L	Fa ₂₂₋₂₆	821.3–821.7	851.2–852.1	--
	Fs ₁₉₋₂₂	336.5–337.6	679.9–680.8	1006.6–1007.5
LL	Fa ₂₆₋₃₂	820.6–821.3	849.9–851.2	--
	Fs ₂₂₋₂₆	334.9–336.5	678.6–679.9	1005.5–1006.6
Sadiya	Fa _{28,97}	819.95	850.20	--
	Fs _{24,47}	335.34	678.49	1004.50

Table 2 Chemical group attribution based on theoretical Raman peak positions compared with Sadiya meteorite [2].

FWHM value 34.3 cm⁻¹ for the pyroxene peak at 1004.50 cm⁻¹ of Sadiya meteorite is higher than the well-crystallized terrestrial pyroxenes [4].

Conclusion

The measured Raman band positions and relative intensities are consistent with chemical composition for olivines and pyroxenes and show influence of shock. The Raman spectroscopic results are complementary to SEM-EDX and compositional analysis. Preliminary assessment suggests that the Sadiya meteorite resemble moderate to strongly shocked ordinary chondrites and it may be classified as LL-5 group.

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