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Lut 009, an H4 (S2, W4) ordinary chondrite meteorite from Lut Desert of Iran

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Abstract

Lut 009 meteorite was found during a trip to Lut Desert of Iran in March,2012, at 30°20.38' N, 59°09.04' E. Chemical compositions of equilibrated olivine ($Fa_{19.3 \pm 0.5}$) and orthopyroxene ($Fs_{16.7 \pm 0.6}$) show that the meteorite sample belongs to H group of ordinary chondrites, while the texture (chondrule petrography and plagioclase size) suggests a petrologic type of 4. The Lut 009 has been very weakly shock altered and has a shock stage of S2. Fe-Ni is completely weathered whereas less than 5 percent of troilite is still present. Therefore, the meteorite has a weathering grade of W4. Magnetic susceptibility is log χ =4.75 (χ in 10^{-9} m^3/kg) and, thus, consistent with a W4 H ordinary chondrite. Here we report description of Lut 009 in the first extended study on a meteorite from Lut Desert. Along with this sample, in-progress investigations of other meteorites from the desert will open a window into the characteristics of meteorite concentrations in this region.

Keywords: Iran, Lut Desert, Meteorite, Ordinary chondrite.

1. Introduction

Since its early days of formation, the Earth was continuously receiving solid objects derived predominantly from asteroidal, cometary and planetary debris. These fragments are ranged in size from interplanetary and interstellar dust particles to boulder-sized chunks and larger objects. They are also capable of forming impact craters. Natural solid objects, larger than a few mm, that reach the Earth's surface are known as "meteorites" (Hutchison, 2004). They are the oldest material in the solar system and in a large variety of parent bodies. Meteorites are especially valuable samples because they can be investigated in the laboratory with a complete set of sophisticated techniques (e.g., Koeberl and Cassidy, 1991), and their study helps us delineate the origin and evolution of our solar system.

At terrestrial environments, meteorites are subject to oxidation and weathering processes that lead to the formation of secondary alteration minerals and finally destruction of the original rock. The rate of meteorite weathering in continents is governed by the climate. However, hot and cold deserts are the most suitable places for preservation of these objects (Bland et al., 2006). In the recent years, some meteorite has been reported from Lut desert of Iran (http://www.lpi.usra.edu/meteor). A stony meteorite was found by the first author in Lut desert at coordinates of 30°20.38' N, 59°09.04' E on March, 2012, lying on the flank of a sand dune near the margin of Rige-e-Yalan and central hamada (Fig. 1). The official name "Lut 009" was approved by "the Meteorite Nomenclature Committee" in February, 2015. Here we present classification and the results of the textural, magnetic susceptibility and mineral chemistry investigations on Lut 009 meteorite sample, with the purpose for further characterization of the meteorite collection of Lut desert.

2. Lut Desert

According to Pabot (1967), approximately 50 percent of Iran's total surface (~1,625,000 km^2) is covered by desert and semi-desert areas, with precipitation less than 50 mm/yr and 50-100 mm/yr, respectively. Lut Desert, a depression surrounded by mountain ranges, extends over an area of about 80,000 km^2 (between latitudes of 28°21' - 32°N and longitudes of 57°30' - 59°55' E and covers 4.9% of the total surface area of the country).

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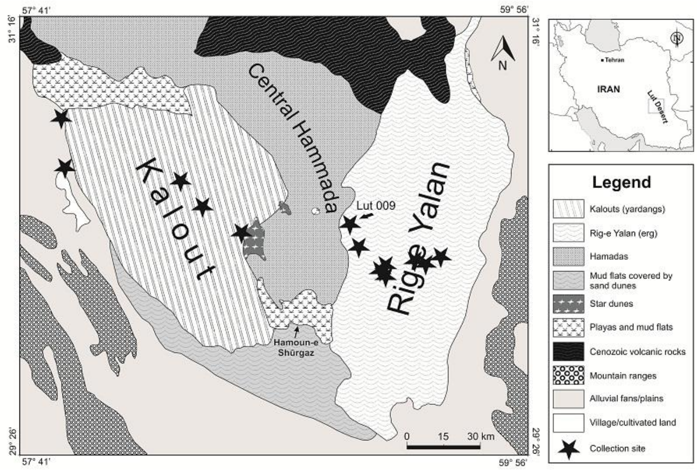

Fig. 1. The map shows central Lut Desert and the location of Lut 009 and other meteorites (from Meteoritical Bulletin)

Based on geographic characteristics, Lut desert is divided into three main units (Mahmoodi, 2002; Ehsani and Quiel, 2008): (1) Northern Lut, characterized by Cenozoic volcanic and sedimentary rocks and vast flat areas, (2) Central Lut, the main unit of Lut characterized by arid to hyperarid conditions, and (3) Southern Lut that is characterized by playas and ravines.

Central Lut comprises three distinct parts: a) the western part occupied by mega-yardangs is known as 'Kalout'; they are some of the world's largest desert landforms separated by large NW-trending wind-swept parallel corridors. These features extend in 140 × 80 km area and were formed by wind and water activities, b) the eastern unit, i.e., Rig-e Yalan (Yalan Erg), is a ~50×100 km sand sea composed of a great massif of dunes and sand rises with heights up to 475 m, and c) the middle part including playas, hamadas and sand sheet type plains.

High temperature, very little precipitation rate (<50 mm/year) and high degrees of evaporation (5000 mm/yr) are some of the main properties of Lut desert. Climate Model Grid (CMG) shows that Lut desert has been the hottest area of the earth in the years 2004, 2005, 2006, 2007 and 2009, with maximum temperatures of 68.0, 70.7, 68.5, 69.0 and 68.6 ^{o}C, respectively (Mildrexler et al., 2011).

According to Pourkhorsandi and Mirnejad (2013), despite vast arid desert areas in Iran (e.g., Dasht-e Kavir, deserts of Yazd and Tabas, Rig-e Jenne desert and Lut), not much attention has been paid to the potential of these Iranian deserts in hosting meteorites. Recent short field surveys to the central Lut Desert by different travel groups have led to the collection of several meteoritic fragments (http://www.lpi.usra.edu/meteor), which points to significant concentrations of meteoritic materials in the area. Climate and surface conditions in Lut desert make it a high-potential region to preserve the meteorites.

3. Methodology

To characterize texture, mineralogy and weathering degree of the meteorite, thin and polished sections were prepared and studied in transmitted and reflected light at the University of Tehran and CEREGE. Using polarizing microscope, mosaic pictures of the meteorite were prepared under transmitted polarized light. Chondrule diameters which are different among different chondrite groups were measured using JMicroVision software based on the mentioned pictures. Reflected polarized light was used to investigate the properties of opaque minerals (primary and terrestrial) and to determine the weathering degree. The chemical composition of ferromagnesian silicates is different among different chondrite groups (Van Schmus and Wood, 1967), and it has been used for the meteorite classification. For this purpose, chemical compositions of olivine and orthopyroxene were determined with JEOL JXA-8200 electron microprobe at California Institute of Technology, using focused electron beam (~1 micrometer in diameter), an accelerating voltage of 15 kV and a beam current of 25 nA. The data were reduced using CITZAF algorithm (Armstrong, 1988). Magnetic susceptibility is another property of meteorites that is different among meteorite groups (Rochette et al., 2012). Magnetic susceptibility was measured at CEREGE using a KLY2 instrument from Agico equipped with both a large ($65 cm^3$) and a small ($10 cm^3$) coil.

4. Results

Lut 009 is a single stone, ellipsoidal in shape (4×2.5×2 cm) and approximately 41 g in weights (Fig. 2). Its surface is covered by a dark-brown desert patina and no fusion crust, usually formed during the atmospheric entry of the object, is remained on. On the surface, a light colored silicate phase can be seen with the unaided eye that might be a macro-chondrule. In cut surface, light and dark colored chondrules are noticeable (Fig. 2). Two highly and moderately weathered facies are present. One contains metal dissolution pits in an orange colored context and the other one exhibit lesser degree of oxidation grey to light brown parts.

Figure 3 shows the mosaic picture of the studied polished section. Olivine and orthopyroxene are the main mineral phases. Very few troilite (<5%) is present and Fe-Ni metal is completely (>98%) transformed to Fe oxides/ hydroxides (Fig. 4). These secondary products occur as weathering veins and patches that are distributed throughout the meteorite (Fig. 5). Olivine and orthopyroxene are different types of chondrules and porphyritic olivine-pyroxene chondrule type as the most common one (Fig. 6). Some olivine grains show uneven darkening but mostly display sharp and uniform extinctions under polarized light. Chondrules in Lut 009 show sharp boundaries with the matrix and the other components. Average apparent chondrule size is 440±280 µm (n=277). In addition to chondrules, olivine and orthopyroxene occur as chondritic fragments. Plagioclase is usually less than two micrometers.

Electron microprobe analysis of olivine and orthopyroxene are presented in Tables 1 and 2, respectively. Average olivine (n=10) and orthopyroxene (n=2) compositions are $Fa_{19.3 \pm 0.5}$ and $Fs_{16.7 \pm 0.6}$, respectively, and both minerals show homogenous compositions. Measured magnetic susceptibility of the sample is log χ =4.75 (χ in 10^{-9} m^3/kg).

Fig. 2. Macroscopic view of Lut 009. Chondrules occur as round dark and light color objects. Metal dissolution pits indicate a high degree of terrestrial alteration.

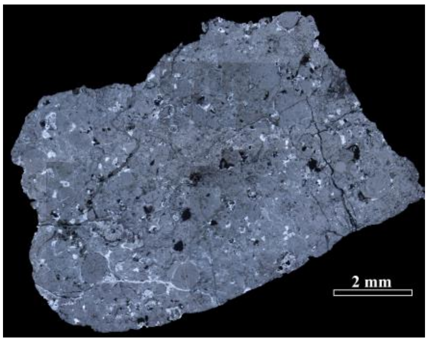

Fig. 3. Mosaic picture of a polished section of Lut 009. Round objects are chondrules and white colored veins and patches are oxidation products of the primary Fe-Ni metal and troilite. Reflected light.

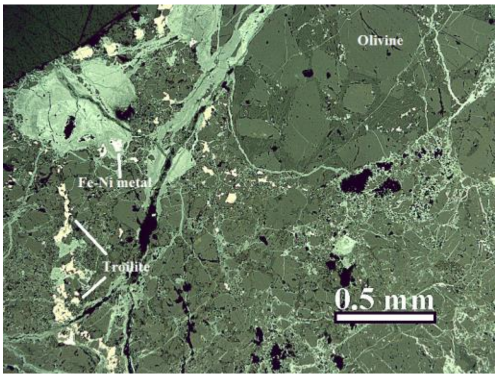

Fig. 4. Troilites (light gray) are less altered than Fe-Ni metal (white) mostly transformed to Fe oxides/hydroxides (dark gray). Reflected light.

Table 1. Representative chemical analyses (wt %) of olivine in Lut 009 ordinary chondrite

Point	SiO_2	TiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	K_2O	Cr_2O_3	MnO	Total	Fa %
193	41.69	0.02	0.00	17.75	40.51	0.09	0.00	0.00	0.06	0.49	100.61	19.73
194	39.41	0.01	0.01	18.50	41.93	0.03	0.00	0.01	0.03	0.54	100.47	19.84
195	39.34	0.02	0.00	18.18	42.13	0.03	0.00	0.00	0.02	0.51	100.24	19.49
196	39.47	0.01	0.00	18.20	41.98	0.03	0.01	0.01	0.03	0.53	100.26	19.56
197	39.67	0.02	0.00	17.47	43.01	0.02	0.00	0.00	0.00	0.42	100.62	18.56
198	39.58	0.01	0.03	17.85	42.54	0.04	0.01	0.00	0.11	0.50	100.67	19.05
199	39.43	0.01	0.00	17.84	42.56	0.02	0.00	0.00	0.01	0.46	100.33	19.04
200	42.65	0.04	2.56	16.39	36.73	0.25	1.46	0.13	0.35	0.41	100.98	20.02
201	41.65	0.04	1.78	16.31	39.19	0.33	0.84	0.14	0.03	0.38	100.67	18.93
204	39.47	0.09	0.00	17.65	42.52	0.03	0.00	0.00	0.02	0.47	100.26	18.89

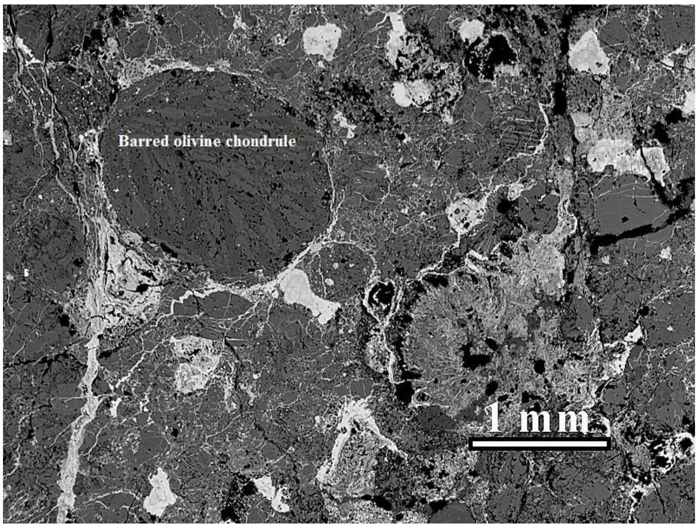

Fig. 5. Terrestrial weathering has affected most of the meteorite. Veins and patches are Feoxides/hydroxides. A barred olivine chondrule can be seen in the view. Reflected light.

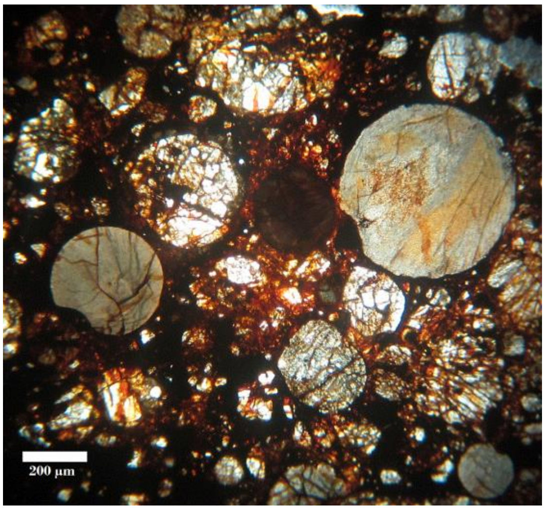

Fig. 6. Different types of chondrules in Lut 009 ordinary chorndrite. Transmitted plain polarized light

Table 2. Representative chemical analyses (wt %) of orthopyroxene in Lut 009 ordinary chondrite

Point	SiO2	TiO2	Al2O3	FeO	MgO	CaO	Na2O	K2O	Cr2O3	MnO	Total	Fs %
202	56.54	0.03	0.19	11.01	30.63	0.80	0.02	0.00	0.27	0.58	100.19	17.27
203	56.58	0.09	0.38	10.18	29.14	2.67	0.19	0.01	0.51	0.49	100.27	16.19

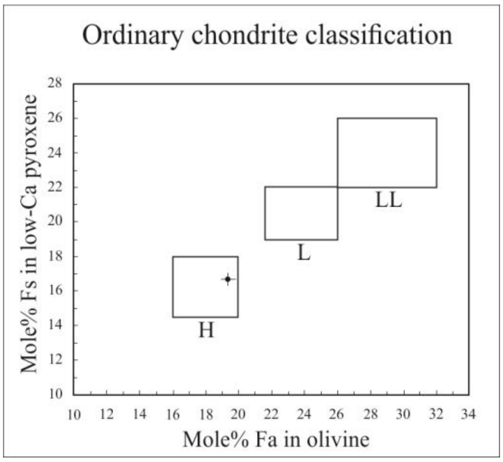

Fig. 7. Average Ca-poor pyroxene versus olivine composition of ordinary chondrites and Lut 009

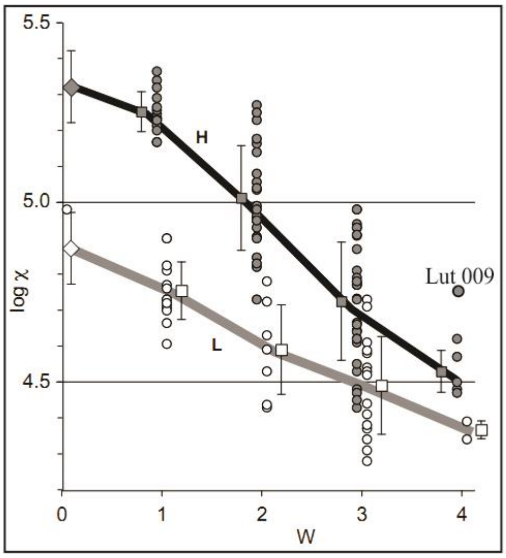

Fig. 8. Log χ as a function of weathering grade for 110 ordinary chondrite finds from the Atacama Desert. Circles are measurements for individual meteorites (solid = H, open = L). Squares are mean values for each weathering grade with associated standard deviation (solid = H, open = L). Diamonds denotes mean values for falls. Lut 009 is in the field of H chondrites. Diagram and description source; Rochette et al. (2012).

5. Conclusions

Lack of fusion crust and severe oxidation of Lut 009 suggest that it has been affected by terrestrial alteration for a long time. Dissolution pits could be the position of former Fe-Ni metal grains, in the most vulnerable phases in terrestrial environments (Buchwald and Clarke Jr., 1989).

The texture and mineralogical components indicate that Lut 009 is an ordinary chondrite. With the homogeneity in olivine composition, chondrule-matrix integrations, size of plagioclase and based on the classification of Van Schmus and Wood (1967), the Lut 009 is a petrologic type of 4. Figure 7 depicts the average olivine and orthopyroxene composition ranges of ordinary chondrites groups and reveals that Lut 009 is an H ordinary chondrite. H ordinary chondrite, in which H stands for “high iron”, is the most common type of found meteorites (Hutchison, 2004).

The presence of uneven darkening in olivine and minor fracturing in Lut 009 are consistent with a very weak shock alteration. This indicates a shock stage of S2, based on classification of Stöffler et al. (1991).

The weathering of Fe-Ni metal and troilite as well as unaltered silicate grains suggest that Lut 009 belongs to the weathering grade of W4 (Wlotzka, 1993). Bland et al. (1997) and Lee and Bland (2004) showed that Fe-Ni metal oxidization is faster than troilite and this is the reason for few occurrence of troilite compared to Fe-Ni metal that is completely transformed into Fe oxides/hydroxides. Such a sever oxidation of the Lut 009 and its occurrence on a sand dune field, which can represent its oxidation in a dry region, indicates a high terrestrial age for this meteorite.

For using magnetic susceptibility and weathering grade date to classify Lut 009, the data were plotted in a diagram of log χ versus weathering degree (Fig. 8) (Rochette et al., 2012). The Lut 009 meteorite is consistent with H ordinary chondrites that are also in accordance with mineral chemistry classification.

The meteorite found and classified in this work has been given the official name of Lut 009 (http://www.lpi.usra.edu/meteor) and it is an H ordinary chondrite with a shock stage of S2 and a weathering grade of W4.

As the number of the reported Iranian meteorites to Meteoritical Bulletin indicated, Lut desert seems to be a suitable place for meteorite preservation in Iran, with a total of 13 meteorites declared to date, most of them in the last 3 years.

Acknowledgments

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