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Composition of elements, oxides and physical properties of meteorites

Raju D. Jadhav
rajujadhav1010@gmail.com

Harishchandra B. Mali
harishchandra.mali@rediffmail.com

ABSTRACT

Three Iron meteorites, namely Sikhote Alin, Campo-del-Cielo, unknown and one stony meteorite Chelyabinsk, were investigated to study their elemental composition, oxide composition and physical parameters in detail and to confirm their originality. XRF analysis carried out for Iron meteorites showed that they contain above 90% Fe and Ni above 4% with other elements in minor quantities and stony meteorite major component showed SiO_2, and Fe_2O_3, with other components in minor quantities. The physical parameters carried out, the images of meteorites in the figures and analysis through XRF, showed that the samples under study are meteorites in origin. This paper reports the work carried out to study the meteorites and their physical properties, and to put on record their elemental composition, their physical properties and through this work to confirm their originality as meteorites on a prima facial basis. A standardless approach has been adapted.

Keywords— *Meteorites, Sikhote Alin, Campo-del-Cielo, Chelyabinsk, Elemental, Oxide composition*

1. INTRODUCTION

Meteorites are rocks from space, i.e., (extraterrestrial) which has escaped the burning process while entering the earth's atmosphere and straight away landed on the surface. The impact of meteorites though harmful on the earth, where the cycle of life is continuously being flourished, yet it has been a boon to the scientist in knowing the history of our solar system how it was formed. Meteorites are studied all over the world to gain immense knowledge of our solar system. They are the fragments leftovers, debris or remnants of our may be an earlier solar system or they may be the debris, leftovers or remnants of our present solar system. In Stone Age time or ancient times, the fallen meteorites and their fragments have been used for making weapons and tools for killing animals and as time passed weapons were made of meteorites and fragments for warfare by kings. Later on, they were also worshipped as messengers of Gods coming from heaven. Even today in remote villages they are worshipped as God's messengers and the fall is kept secret. There are some incidences, where the fall of large size meteorites has changed or destroyed the earlier era on the earth or ecosystem. For e.g., the extinction of dinosaurs is related to the impact of a large meteorite, recently, fall of a meteorite have caused heavier damage to life, crops and soil and destruction of wealth etc.

1.1 Brief history of Meteorites

[1] Sikhote Alin iron meteorite: A meteorite of iron nature fell on the Sikhote Alin Mountains, southeastern parts of Russia, in 1947. Sikhote Alin meteorite fall was observed by many people and large quantities of fragments of this meteorite fallen on the mountains of Sikhote Alin were recovered. It is known that though the iron meteorite fall has been observed earlier, yet this type of fall was the first of its kind observed by a large number of people. The fall of this meteorite took place on February 12th 1947(1).

[2] Campo-del-Cielo Iron meteorite: The Campo-del-Cielo refers to a group of iron meteorites. This meteorite was known to the locals of that area where it fell. The fragments of this meteorite made craters where iron fragments were found in larger quantities. The age of the crater as estimated was formed some 4,000 – 5,000 years ago and was reported only in 1576(2).

[3] The unknown iron meteorite sliced part: No detail information is available except that it is an iron meteorite cut in sliced form.

[4] Chelyabinsk stony meteorite: The Chelyabinsk meteor was a bolide type, caused by a near-earth asteroid of an approximately 20mtrs, which entered the earth's atmosphere and exploded over Russia on February 15th 2013. The fall of this meteorite was found to be due to Air Burst of a meteor (3).

1.2 Some of the works carried on meteorite studies

Meteorites [1] represent the only cosmic (extraterrestrial) material available for direct study in the laboratory [(4)]. Iridium, a PGE (Platinum Group elements i.e., Iridium, Gold, Platinum, Rhenium and Osmium) is present in small amounts in the earth's crust and upper mantle but is more abundant in both the earth's core and meteorites[(5)]. Curiously, many earlier people did not seem to have made the connection between fireballs and stones from the sky, yet in some historical periods, the worship of meteorites was common. Images of sacred stones, possibly meteorites, appear on many Gre co-Roman coins [(6)]. A major problem in identifying impact events is that virtually all the features and careful detailed work are often necessary to resolve the differences [(7)]. For billions of years, meteorites in the environment of space have resisted most weathering. They are far removed from the damaging effects of water and oxygen. But the earth is an alien environment for a meteorite. Under normal terrestrial conditions, they cannot survive long after impact without measures being taken to preserve them [(8)]. Meteorites are rocks, like terrestrial rocks, the majority of meteorites are made of aggregates of crystalline minerals [(9)]. The dark and light lithologies have virtually identical mineralogical and bulk oxygen compositions [(10)]. Nickel-Iron is practically absent from terrestrial rocks; the common minerals in meteorites are largely magnesium-iron silicates, whereas, in the Earth's crust the commonest minerals are quartz and aluminosilicates [11)]. It is likely that meteorites weather more intensely in wet and humid areas, and that, the older meteorites are stronger weathered. Temperature fluctuations from summer to winter and between day and night could affect the weathering intensities [(12)]. Because the analysis was carried out in the air at atmospheric pressure, the concentration of elements which are presented in the air and also in meteorite fragment i.e., oxygen, nitrogen and hydrogen and did not achieve in concentration calculation [(13)]. Iron meteorites, or irons, as they are commonly known are actually a combination of iron (Fe, the chemical symbol for iron), Nickel (Ni), and Cobalt (Co). Iron is the predominant metal combined with five percent up to fifty percent Nickel (as an alloy with iron in most iron meteorites) and a trace of Cobalt [(15)]. Larger stones and irons reach right to the ground. They are little slowed down and hit the surface with a speed close to their cosmic velocity. The shock is then very violent and an impact crater is formed. Sound phenomena frequently accompany the fall of a meteorite [(15)]. Meteorites are assigned to three main categories, Irons (or siderites) consist primarily of metal; stones (or aerolites) consist of silicates with little metal; stony irons (or siderolites) contain abundant metal and silicates [(16)]. Minerals occurring in meteorites include phosphides and phosphates, sulphides and sulphates, carbides and carbonates and silicides and silicates. Meteorites also contain minerals formed by shock metamorphism and terrestrial weathering of the primary minerals [(17)].

2. METHODOLOGY

Physical features like luster, shape noted down, dimensions taken with the help of a foot ruler and noted down, the physical parameters like the mass were taken on a weighing balance and volume was taken by displacement of water method in a measuring cylinder of borosilicate make and density was calculated. Finally, after physical parameters taken, the meteorite samples were sent for XRF analysis for elemental and oxide composition.

2.1 Scope of work

To carry out detail work on meteorites regarding their physical parameters, physical features and XRF analysis for elemental composition and to confirm the originality of samples under study.

2.2 Experiments

Physical features like luster, shape and dimensions with the help of foot ruler were carried and noted down. Mass was taken in a Radwag balance, volume was taken by displacement of water method in a measuring cylinder of borosilicate make, and finally, density was calculated by using the formula m/v = density g/cm³. After physical parameters, XRF analysis was carried out for elemental composition.

2.3 Experimental results

Physical parameters carried out for iron meteorites are given in Table 1, and in the figure, 1and 2, metallic luster is clearly observed. Density value also agrees well with iron meteorites of standard type table 1. From luster and density, the class was known in table 1. XRF analysis carried out, the result in Table 2, shows that the iron meteorites have Fe to be above 90 % mass and Ni to be above 4% mass with other elements in minor compositions. Similarly, the stony meteorite, Table 2 and 3, shows that the major component is SiO_2 and Fe_2O_3 with other oxides in minor compositions. The luster and density of stony meteorite are given in table 1, and the element composition given in table 2.

3. RESULTS AND DISCUSSIONS

From figure 1and 2, metallic luster is clearly observed which is a characteristic feature or peculiarity of iron meteorites. From observation and table 1 physical parameter, iron meteorites show metallic luster, whereas stony meteorite show earthy luster, the density calculated for iron meteorites table 1 also shows that they agree well with iron meteorites studied which is also a characteristic feature or peculiarity of iron meteorites. These two properties or peculiarities of iron meteorites points to the originality of Sikhote Alin and Campo-del-Cielo both iron meteorites to be genuine meteorites. The density of unknown iron meteorite also agrees well with the density of iron meteorites. The XRF analysis result in table 2, shows that for Sikhote Alin meteorite, 10 elements were detected, where Fe was found to be 93.7 mass % and Ni was found to be 4.79 mass %. The values of elements like Fe, Ni and P in Sikhote Alin iron meteorite this study and that by Plavčan et al. are more or less in good agreement, which shows that the originality of the sample to be genuine. Also the values of Ni and Fe in iron meteorites namely Sikhote Alin, Campo-del-Cielo and unknown iron meteorite this study are close to the values mentioned by Mason for Ni and Mean Fe value[(11)], which suggest the samples under study are meteorites. The Sikhote Alin meteorite which fell in 1947 was a fall witnessed by many people and many fragments were recovered immediately after the fall, hence the chances of being contaminated were negligible. Campo-del-Cielo an iron meteorite was a find; hence there was every chance of contamination and weathering But Chelyabinsk was a fall and hence its fragments were recovered as soon as it fell, hence chances of its contamination were negligible. Some of the researchers are in the opinion that stony meteorites represent the crust of the terrestrial planets, whereas iron meteorites represent the core of the planets.

The results by XRF analysis for Campo-del-Cielo iron meteorite, 11 elements were detected, table 2, in which Fe was found to be 90.4 mass %, Ni was found to be 5.75 mass % and Co was found to be 0.921 mass %. From this originality of iron, meteorites can be confirmed. The values of elements of Campo-del-cielo this study and the values of Campo-del-cielo studied by earlier researchers when compared, the ratios and the differences were found to be marginal, which also proves the originality of samples to be true.

The results obtained by XRF analysis for unknown iron meteorite, 9 elements were detected, table 2, in which Fe was found to be 93.0 mass %, Ni was found to be 4.29 mass % and Co was found to be 0.0013 mass %, with other elements in minor quantities which confirms the originality of sample to be genuine meteorite. Though the unknown meteorite has Fe, Ni and Co values nearly equal to iron meteorite studied and the density parameter in table 1 also points to the high density which iron meteorite has, the metallic luster is not observed due to the polished part cut into sliced and also since it is an iron meteorite, the weathering process (rusting effect of an iron) can be clearly seen. From these interpretations, it can be inferred that the unknown meteorite is a genuine meteorite of iron nature.

The results by XRF analysis for Chelyabinsk meteorite in table 3 shows that SiO_2 is 29.2 mass %, Fe_2O_3 is 46.4 mass %, MgO is 6.47 mass %, SO_3 is 5.07 mass %, Al_2O_3 is 3.80 mass %, CaO is 2.07 mass %, P_2O_5 is 2.88 mass %, NiO is 1.39 mass % and Cr_2O_3 1.20 mass % with other oxides in minor composition, whereas the elements in table 2 shows that Fe is 54.1 mass %, Si is 22.7 mass %, Mg 6.50 mass %, S is 3.38 mass %, Al is 3.35 mass %, Ca is 2.47 mass %, P is 2.10 mass %, Ni is 1.82 mass %, Cr is 1.37mass % and Cl is 1.31 mass %.

In Stony meteorite Chelyabinsk, the results obtained by XRF analysis shows that 13 elements were detected Table 2, out of which Si, Al, Ca and S are found to be more or less the same with respect to Mason elemental value and the rest are found to be higher than Mason values[11]. Out of 13 elements detected in Chelyabinsk, only S was found to be lower than Al-Kathiri value [12] and Nair et al value[5], where the rest were found to be higher in percentage. The value of Fe in stony meteorites is between 18 -25%. The highest value of Fe is up to 28% in H chondrite [18]. Out of 13 elements detected in Chelyabinsk, only Mg was found to be lower than Akhnoor meteorite [19], Kaprada Meteorite [20] and Taglish lake meteorite [21], the rest of the elemental values were found to be higher in percentage, which means, the sample under study is a genuine meteorite The values of Fe in Chelyabinsk is 54.1 mass % which is more than that found in stony meteorite. It is also to be considered that Chelyabinsk stony meteorite was a fall and not a find i.e., it was observed by many locals where it fell and immediately it was picked up. Hence the chances of its being contamination are negligible. This type of stony meteorite having the highest content of Fe is noteworthy. The analysis by XRF was repeated again to confirm the value of Fe. Yet it shows the highest percentage not found in stony meteorites as per analysis carried by different researchers. The values of Chelyabinsk this study agrees more or less well with other stony meteorites except for Fe and some other elements [11,5]. From the observation of the images in figures 1, 2, 3 and 4 of all the meteorites under study points to the originality of meteorites. Vinogradov pointed out that the density of stony meteorite is lower than that of the terrestrial rocks [18]. The density of Chelyabinsk, the stony meteorite is 1.668g/cc, table 1, which is found to be lesser than terrestrial rocks i.e., the density of lodestone (earth rocks) is found to be 3.87g/cc. From this, it infers that the sample under study is a genuine meteorite.

4. CONCLUSION

From the figures 1, 2, 3 and 4, the images observed points to iron and stony meteorites, the metallic luster observed for iron meteorites, the physical characteristics of meteorites density and luster, from the analysis and results obtained through XRF analysis, physical parameters and finally the discussion, all these features points to originality of meteorites to be genuine and hence it is concluded and confirmed that the samples under study are original meteorites.

Falling stones i.e., meteorites falling on the earth surface is a natural process. It is not related to any other event, other than a natural process. It is not a precious metal or as a source of income. Hence it should not be hidden or the fall or find should not be kept secret. It must be believed that it only rocks from space of alien nature. If meteorite fallen or find is known, it should be immediately reported to the respective Government Authority, taken every care to preserve it, not to contaminate it or destroy it in any circumstances, because it is the only hand specimen component made available by nature to scientist and researchers to study in detail regarding the birth of our solar system and our earth formation i.e., past history of our solar system, how was it formed? It helps to explore in depth how at the time of birth of our solar system, what was the composition of elements? How they combined to form into a large globe of complete solid mass, and how life came into existence on the earth. The meteorites are a wealth of knowledge. This study can be helpful to the common man to differentiate a meteorite from earth rocks or identify the meteorites from earth rocks (terrestrial rocks).

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APPENDIX

Table 1: Physical parameters of meteorites

S. no.	Sample Name↓ Physical Parameters→	Luster	Density g/cm³	Dimensions in cm	Class	Shape
1	Sikhote Alin Meteorite (Iron)	Metallic	6.2142	2.3 x 1.6 x 1.1	Iron	Irregular
2	Campo-del-cielo meteorite (Iron)	Metallic	5.9409	2.0 x 1.4 x 1.5	Iron	Irregular
3	Unknown Iron meteorite	Metallic	7.9558	2.7 x 1.7 x 0.3	Iron	Sliced flat
4	Chelyabinsk meteorite (stony)	Earthy	1.668	0.3 x 0.2 x 0.1	Stony	Irregular

Table 2: Elemental composition of Meteorites by XRF in mass %

S. no.	Elements↓ Legend→	1	2	3	4
1	Fe	93.7	90.4	93	54.1
2	Ni	4.79	5.75	4.29	1.82
3	Si	0.475	0.798		22.7
4	Al	0.405	0.234	0.364	3.35
5	P	0.399	1.77	0.212	2.1
6	Cu	0.12			0.116
7	S	0.0664	0.121	1.11	3.38
8	Zr	0.012			
9	Cr	0.0095	0.0054	0.0542	1.37
10	Mo	0.0095	0.0088	0.101	
11	Co		0.921	0.0013	
12	Au		0.0033		
13	W		<0.0001	0.895	
14	Ca				2.47
15	Mn				0.574
16	Ti				0.164
17	Mg				6.5
18	Cl				1.31
Total		99.9864	100.0115	100.0275	99.954

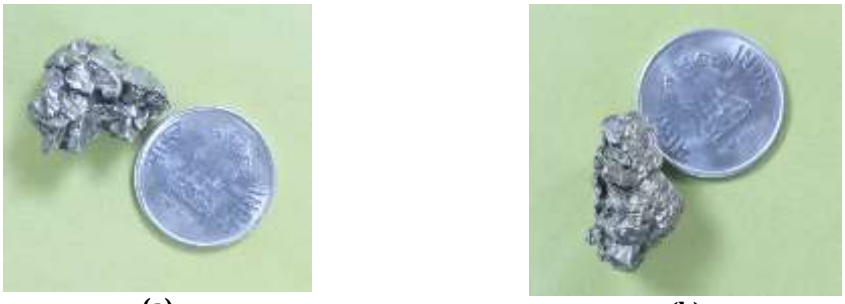
Legend:
1. Sikhote Alin Iron meteorite
2. Campo-del-Cielo Iron meteorite
3. Unknown Iron meteorite
4. Chelyabinsk stony meteorite

Table 3: Oxide composition of Chelyabinsk meteorite by XRF in mass %.

S. no.	Oxides	Result	Mass %
1	Fe_2O_3	46.4	Mass %
2	SiO_2	29.2	Mass %
3	MgO	6.47	Mass %
4	SO_3	5.07	Mass %
5	Al_2O_3	3.8	Mass %
6	P_2O_5	2.88	Mass %
7	CaO	2.07	Mass %
8	NiO	1.39	Mass %
9	Cr_2O_3	1.2	Mass %
10	Cl	0.785	Mass %
11	MnO	0.445	Mass %
12	TiO_2	0.165	Mass %
13	CuO	0.0871	Mass %
Total		99.9621	Mass %

(a) **(b)**

Fig. 1: (a) and (b) fragment of Sikhote Alin meteorite, an iron meteorite



(a) **(b)**

Fig. 2: (a) and (b) Fragment of Compo-del-cielo meteorite, an iron meteorite

(a) **(b)**

Fig. 3. (a) and (b) Fragment of unknown iron meteorite

(a) **(b)** **(c)**

Fig. 4: (a), (b), (c) Fragment of Chelyabinsk meteorite, a stony meteorite

