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# A study of meteorites on the basis of their source and origin

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## ABSTRACT

***Representative samples of meteorites namely, 1) Sikhote Alin (iron meteorite), 2) Campo-del Cielo (iron meteorite), 3) Nantan (stony iron meteorite), 4) Morocco (stony iron), and 5) North West African meteorite (likely to be of chondrite in nature), were investigated to understand their source and origin with respect to their physical properties and chemical compositions. XRF Analysis carried out showed that 1) Sikhote Alin contains Fe - 89.0%, Ni - 4.83% and Si - 3.51% with other elements in minor compositions, 2) Campo-del Cielo contains Fe - 97.4%, Ni - 1.15% with other elements in minor compositions., 3) Nantan contains $Fe_2O_3$ - 66.8%, $SiO_2$ - 22.7%, Aluminum - 6.380%, Nickel - 1.760% with other oxides in minor compositions 4) Morocco meteorite contains $Fe_2O_3$ - 45.7%, $SiO_2$ - 17.2%, CaO – 14.2%, MgO – 10.9%, $SO_3$ - 3.80%, $Al_2O_3$ and NiO – 2.42% and 5) North West African meteorite (N.W.A.) contains $SiO_2$ - 39.9%, $Fe_2O_3$ - 27.4%, MgO – 20.8%, $Al_2O_3$ - 6.040%, CaO – 2.34%, $SO_3$ - 1.610% and NiO – 0.734%, with other oxides in minor compositions. Objects fallen on earth so far has been given a common name 'meteorites' The authors of this paper broadly classified meteorites into 'Seteorites' and 'Uniteorites'. The source of 'seteorites' is from our solar system and the source of 'uniteorites' is from beyond our solar system. Physico - chemical nature of 'seteorites' and 'uniteorites' are different as per their source. This paper aims at carrying out a detailed study on seteorites (meteorites), to understand their source, origin and their distribution in the solar system with respect to their physical properties and chemical compositions on preliminary basis.***

***Keywords****. Iron Meteorite, Stony Iron Meteorite, Stony Meteorite (Chondritic in Nature), Source And Origin, Physical Properties And Chemical Compositions*

## 1. INTRODUCTION

Any rocks in space are known as meteoroid. When it comes near the Earth, due to Earth's gravity is pulled towards it and starts burning due to friction with the atmosphere, the flash of light seen is the meteor. The word "meteor" comes from the Greek word meteora or meteoros[1]. When the unburnt part or fragment of the same rock falls on the earth, it is known as meteorite. Meteorites may possibly be the remnants or debris of our earlier solar system or it may possibly be the leftover debris of our present solar system. Millions of these rock fragments are found in the asteroidal belt, existing between Mars and Jupiter, due to unknown forces, are thrown out of the asteroidal belt and wander through the solar system. Some researchers are of the opinion that these fragments existing in the asteroidal belt may be the fragments of an exploded planet once upon a time, existed between Mars and Jupiter, but due to some unknown event, was shattered to fragments and the fragments were found to be spread, what is today known as asteroidal belt.

Meteorites are considered to be the extra-terrestrial bodies of universe, but meteorites from our solar system being native are termed as 'Seteorites'. 'Seteorite' word came from meteorite by replacing 's' in place of 'm', where 's' indicates our solar system. Similarly, meteorites beyond our solar system are termed as 'Uniteorite'. "Uniteorite' word came from meteorite by replacing 'uni' in place of 'm' where 'uni' indicates extra-terrestrial bodies beyond our solar system, so that it is easier to recognize meteorites from which source it has come because chemical and physical nature is different according to the source and origin.

Seteorites are meteorites within our solar system and Uniteorites are meteorites beyond our solar system. Today there are no samples of uniteorites fallen on earth. Uniteorites are responsible for exchange of chemicals and biological substances in universe for example comets (long period), coming from Interstellar space.

It is postulated that the life on earth originated from Uniteorites bringing some life sustainable divine chemicals that build up life building blocks, from which life evolved on earth.

 

### 1.1 Some of the previous works carried out on meteorites.

Krinov studied meteorites and states that studies of the chemical composition of meteorites made possible the conclusion that their composition is the same as that of the Earth[2]. Reynolds states that several sources of meteorites are found in the solar system[1]. Krinov carried out a detailed study on meteorites and states that it should also be remembered that, up to the present, only craters formed by the fall of iron meteorites have been discovered (identified as such because fragments of iron meteorites were found in these craters[3]. Mason studied meteorites and mentions that current classifications of meteorites are based on mineralogy and structure[4]. Mckenzie studied meteorites and mentions that most meteorites are known to originate from the asteroid belt and from only about 150 different asteroid, or 'dwarf planets'[5]. Norton carried out a detailed study on meteorites and states that sometimes during impact, the entire meteoroid fractures but amazingly does not shatter[6]. Norton studied meteorites and mentions that early chemical analysis revealed the celestial origin of meteorites[7]. Brown et al. studied Tagish Lake and concludes that Tagish Lake is a new type of Carbonaceous Chondrite[8].

### 1.2 Brief History of meteorites

**(i) Sikhote Alin**

This meteorite is iron in nature. This meteorite fell in the Sikhote Alin Mountains of South eastern Russia in 1947. The fall of this meteorite was observed by many people. Large quantities of this meteorite fragments were fallen and were recovered[9].

**(ii) Campo-Del-Cielo**

This meteorite is iron in nature. This meteorite was first written about in 1576 by Spanish Conquistadors, when the unearthly origin of these non-native iron masses was not yet understood. In terms of the amount of material recovered, Campo-del-cielo is among the largest meteorite showers known[10]. It was extracted in 1980 and, at the time, was estimated to weigh about 37 tonnes. This made it the second heaviest meteorite after the 60-tonne meteorite[11]. Scientist believes that like other iron meteorites, the campo-del-cielo mass probably originated within the asteroidal belt between Mars and Jupiter[12]. It refers to a group of iron meteorites that are found in an area of the same name about 1000 km northwest of Buenos Aires, Argentina[13].

**(iii) Nantan – China**

This meteorite is stony iron in nature. It is thought that the meteorite broke up as it fell to Earth in the year 1516, scattering debris over a wide area. This piece of meteorite was found after 1958 in Nantan County, Guangxi, China[14].

Since there was a shortage of iron and knowing that meteorites contain iron, hence the meteorites were dug up. Luckily the melting point was too high and the meteorites was spared[15].

**(iv) Morocco (stony iron nature)**

No information about this meteorite is known, except that it was fond in Morocco.

**(v) North West Africa. (N.W.A.)**

This meteorite is stony (Chondritic) in nature. This meteorite was found inNorth West Africa. It is considered a stony type of meteorite called a chondrite. The chondrite name comes from spherical, silicon containing particles within the meteorite called "chondrules". These chondrules make chondrite meteorites distinct from other types of rocky meteorites. Chondrules are composed of some of the oldest materials within the solar system[16].

### 1.3 Scope of work

To understand and know the source and origin of meteorites with on the basis of their physical properties and chemical compositions.

## 2. METHODOLOGY

The fragments under study, their physical properties were noted down. After this, the meteorites samples were sent for XRF analysis, (table 2, 3, 4 and 5). The samples under study were weighted on a standard balance and the weights of each meteorite were noted down. Their physical properties were noted down. The volume was taken by water displacement method using a standard measuring cylinder of borosilicate make and the density was calculated, using the formula D = M/V g/cc. (Table 1). The Morocco meteorite, the sample being big, a small piece was taken out for analysis purpose, especially volume, which was otherwise difficult to carry out as the sample is big enough.

### 2.1 Experimental Results

The physical parameters carried out on meteorites are shown in table 1. The chemical compositions of iron, stony iron and stony nature of meteorites by XRF carried out are shown in table 2,3,4,5 and 6. Difference between stony iron Nantan and Morocco has been given in table 7 and difference between stony (rocky) type of meteorites Chelyabinsk and stony (chondritic) North West Africa (table 8).

## 3. RESULTS AND DISCUSSIONS

### (a) Sikhote Alin meteorite

As per physical features (table 1), and the images in the fig. 1and fig. 5, it is seen that the metallic lustre is clearly observed, which is a peculiar feature of iron meteorites. Also, the high density of Sikhote Alin meteorite (7.5955g/cc) confirms its true nature of being an iron meteorite.

As per chemical compositions (table 2), it is seen that the Iron (Fe) content is 87.6%, Nickel (Ni) content is 4.74% and Cobalt (Co) content is 0.973%, which also confirms its true nature of Sikhote Alin meteorite being of iron nature. Silicon (Si) is found to be higher i.e., 4.16%, such a high percentage of Silicon (Si) is not found in iron meteorites. This may possibly be due to impurities. Sikhote Alin meteorite is fully of ironic nature.

### (b) Campo-del-Cielo meteorite

As per physical features (table1), and the images in the fig. 2 and fig. 6, it is seen that the metallic lustre is clearly seen, which is a peculiar feature of iron meteorites. Also, the high density of Campo-del-cielo meteorite (7.908g/cc) confirms its true nature that Campo-del-cielo being an iron meteorite.

As per chemical composition (table 3), it is seen that the Iron (Fe) content is 90.8%, Nickel (Ni) content is 5.9%, Cobalt (Co) being 0.984%, which also confirms the true nature of Campo-del-cielo meteorite being of iron nature. Campo-del-cielo meteorite is fully of ironic nature.

**The source and origin of iron meteorites (Sikhote Alin, Campo-del-cielo).**

All the meteorites fallen on earth are found to be either from Asteroidal belt, Moon or Mars. Hence their place of origin in the solar system either lies in the Asteroidal belt, the Moon or Mars. Hence objects of extra-terrestrial nature fallen on earth, the majority of it is known to be from asteroid belt.

Iron nature of meteorites represents or show similarity to core of terrestrial planets in chemical compositions. The density of these types of meteorites also reflects the density of core of terrestrial planets. Hence it is possible that they may be the leftover debris of terrestrial planets.

The asteroidal belt must be the source and origin of iron nature of meteorites. i.e., being the fragment of either bigger asteroid or the leftover debris. Hence all the iron nature of meteorites of whatever chemical compositions may have, are all members of asteroidal belt components. In other words it can be said that, the asteroidal belt may be the store house of iron nature of meteorites.

As per chemical composition of Sikhote Alin iron meteorite (table 2), Silicon (Si) is found to be in high percentage than Campo-del-cielo iron meteorite (table 3), and even other elements show little variation. This difference shows that their distribution in the asteroidal belt is placed differently or certain distribution pattern may exist, where each type of iron nature of meteorites are found to be segregated separately from each other may be in large numbers.

**(c) Nantan Meteorite (China), stony iron nature**

As per physical features (table 1), and the images in the fig.4, 7 and 8, , it is clearly seen that the meteorite had undergone a tremendous heat factor, where the burnt part is clearly visible, which is known as fusion crust. One side it looks like stony or rocky type ( brown in color) on the other side, where it has been burnt, it shows irony type, where it has also been rusted. The black burnt part or the rusting of iron is clearly visible from the figure (fig.7 and 8), which is a peculiar feature of iron, which indicates that Nantan meteorite is of stony iron nature. The density of Nantan meteorite which is 4.9436g/cc, which is found to be similar to stony iron nature of meteorites and hence, it indicates the true nature of Nantan meteorite to be of stony iron nature.

As per chemical composition (table 4), shows that $Fe_2O_3$ content is 59.0%, $SiO_2$ content is 28.7%, NiO content is 1.210%, $Co_2O_3$ content is 0.402% and $Al_2O_3$ content is 8.44%. The high percentage of $Fe_2O_3$ and $SiO_2$ confirms its true nature that Nantan meteorite being of stony iron nature. Nantan meteorite is of intermediate in nature (stony iron) i.e., more metallic than rocky or earthy because high percentage of $Fe_2O_3$ than $SiO_2$.

**Source and origin of stony iron nature of meteorites (Nantan).**

From the studies carried out, it is known that stony iron nature of meteorites represents the mantle part of terrestrial planets; Nantan meteorite being of stony iron nature therefore the chemical composition of Nantan meteorite is similar to mantle part of terrestrial planets. Hence the source and origin of stony iron nature of meteorites can also be postulated to be in the asteroidal belt, similar to iron nature of meteorites. The density of mantle part of terrestrial planets being higher than crust but lower than core, similarly the density of stony iron nature of meteorites is also found to be higher than stony (rocky) nature of meteorites but lower than iron meteorites. Hence it infers that these types of meteorites may also be the leftover debris of terrestrial planets.

**(d) Morocco meteorite**

As per the physical features (table 1) and fig. 13, Morocco meteorite has brown colour, with some black patches on the surface, having a density of 3.43 g/cc and having earthy lustre. Since the meteorite fragment is large, it was difficult to take volume hence a small piece was taken and the weight and volume was taken and then density was calculated.

As per the chemical compositions (table 6), shows that $Fe_2O_3$ is 45.7%, $SiO_2$ is 17.2%, CaO is 14.2%, MgO is 10.9%, $SO_3$ is 3.80%, $Al_2O_3$ is 2.93, NiO is 2.42% with other oxides in lesser percentage.

Nantan and Morocco are stony iron in nature and hence their source and origin are postulated to be from asteroidal belt, because they both show resemblance to mantle part of terrestrial planets, their density is also similar to the density of mantle part of terrestrial planets. They are also postulated to be the leftover debris of terrestrial planets. In short, it can be stated that iron nature of meteorites and stony iron nature of meteorites can be postulated to be the members of asteroidal belt or in other words it can be said that the asteroidal belt may be store house of iron and stony iron nature of meteorites. It is difficult to understand the place of distribution in the asteroidal belt from the chemical composition and physical features, as the physical features vary according to the distance from the sun, whereas the chemical composition does not vary much, i.e., the variation in elemental composition can give us the distribution pattern of these types of meteorites in the asteroidal belt, where they may be found in large numbers. Morocco meteorite is of intermediate in nature (stony iron), i.e., high percentage of $SiO_2$ than $Fe_2O_3$ and hence reflect rocky nature than metallic nature, Nantan meteorite being also of intermediate in nature (stony iron), but shows high percentage of $Fe_2O_3$ than $SiO_2$, which means both the meteorites of stony iron nature of the same class, yet they show difference in their chemical and physical properties, i.e., Morrocco meteorite (stony iron) is more of rocky nature than ironic nature (fig. 13), whereas Nantan (stony iron) reflects more of ironic nature than rocky nature (fig. 4). This needs to be studied in more detail.

It is also to be stated that if the chemical composition of iron and stony iron nature of meteorites were not similar to the core and the mantle part of terrestrial planets, then it would be very difficult to search their source of origin.

 

**(e) North West Africa (N.W.A.) meteorite.**

As per physical feature (table 1) and fig 3, the color of N.W.A. is found to be chocolate brown, having a density of about 4.4384g/cc and having earthy lustre. The observation through student microscope of 20X and photograph taken through 64 mega pixel mobile camera, surface feature shows some granules like structures, it is possible this may be the chondrules (fig. 9,10,11 and 12), which points to chondritic nature of stony meteorite.

The chemical composition (table 5) shows that metallic oxide content is $SiO_2$ - 39.9%, $Fe_2O_3$ - 27.4%, MgO – 20.8%, $Al_2O_3$ - 6.04%, CaO – 2.34$, $SO_3$ - 1.61%, NiO – 0.734% etc. $SiO_2$ and MgO is found to be in higher percentage as compared to Chelyabinsk (stony meteorite)[17]. The physical features and chemical composition shows that N.W.A. belongs to a chondritic nature of meteorites. Since the percentage of $Fe_2O_3$ is found to be high, it is likely that it may belong to H type of chondrites. N.W.A. since has high percentage of $SiO_2$, hence fully stony (rocky) or earthy, color is also earthy and hence reflect earthy nature. Stony meteorite or chondrites are brittle in nature i.e., when they impact, they break into smaller fragments, but iron meteorites will not break into smaller fragments when it impacts. This is one of the major differences between stony and iron meteorites.

**Source and origin of stony (chondritic nature) meteorite (N.W.A.).**

Since stony meteorites of chondritic nature contains chondrules, which are considered to be the oldest components in the solar system, hence these types of meteorites therefore are the oldest of meteorites known, especially the ones containing Carbon (C), known as carbonaceous meteorites. But as per some researchers opinion, meteorites in general fallen on earth from time immemorial are the fragments of an exploded planet once upon a time existed between Mars and Jupiter, but due to some unknown event exploded and the fragments all spread and circled in the same orbit where, broken planet once existed, which is now known as asteroid belt, where million fragments of rocks of different sizes and shapes exist and revolve around the sun.

The asteroid belt objects is postulated to be the leftover debris of terrestrial planets that came into existence only after the planets were formed i.e., after the formation of their parent body. Hence the objects lying or existing in this belt cannot be the oldest. But if chondrites are considered to be the oldest of meteorites known, then they must possibly be the leftover debris of a comet short period comets, (which lie beyond the orbit of Neptune), or long period comets (which lie on the boundary of our solar system) i.e., Oort cloud or components of Interstellar Dust Particles (as some comets come from Interstellar space). Also they are said to be the oldest because these meteorites contain Carbon (C) and Silica (Si) and these two components are also found in comets. As comets are also part of our solar system and they frequently visit our solar system, leaving their debris in the planets path, when coming from far reaches of the solar system or Interstellar space.

It is also possible that the chondritic nature of meteorites were may be the first formed components of present solar system or remnants or leftover debris of earlier solar system.

Though there may be oldest rocks on terrestrial planets, yet they do not show any resemblance or similarity to chondrite types of meteorites, similar to iron, stony iron and stony nature of meteorites in chemical composition. Carbon and Silica, which is the major components in chondrite types of meteorites especially the carbonaceous ones, is not found in terrestrial rocks, however old they may be. Hence the source and origin of chondrite types of meteorites infers to be from beyond our solar system.

Brown et al. showed that C1 and CM and Tagish lake meteorites of carbonaceous nature, show chemical composition value very close to the chemical composition value of the sun[8]. This infers that the chondrites nature of meteorites especially the carbonaceous ones, their origin lies in the solar nebula as it is known that sun was also formed from solar nebula. Or are they then the pre solar grains? A detailed study is required to know and understand their source and origin. What is their exact place in the solar system? Are they the fragments of earlier solar system remnants? Or are they the leftover debris of cometic materials? Or are they the components of Interstellar dust particles?

From the table 8, it is observed that difference between stony meteorites (rocky) and chondritic nature is shown. There is a major difference between the two.

**(f) Source and origin of stony (rocky) nature of meteorites (Chelybinsk).**

The physical parameters and chemical composition of Chelyabinsk (stony meteorite) has been given in Jadhav and Mali's paper[17]. As per the studies, it is known that the stony (rocky) nature of meteorites represents or is similar to crust of terrestrial planets. Hence their source of origin can also be postulated to lie in the asteroid belt. The physical features and chemical composition of stony meteorites more or less shows similarity to the crust of terrestrial planets. Hence the possibility or chances of its being found in the asteroidal belt is more plausible. They may be the fragments of bigger and larger asteroid lying or existing in the asteroidal belt.
From the chemical composition of Chelyabinsk (stony meteorite) $Fe_2O_3$ is found to be in higher percentage with respect to other oxides[17]. As per the studies conducted through this paper, it is inferred that asteroid belt is the store house of iron and stony iron nature of meteorites. Iron and stony iron (from the name itself) shows that they contain high percentage of Iron (Fe). From this it indicates or shows that stony meteorite like Chelyabinsk having higher percentage of $Fe_2O_3$ may possibly be the member of asteroid belt, but the density of Chelyabinsk meteorite is found to be lower than terrestrial rock. Chelyabinsk (stony) meteorite shows similarity to terrestrial planets crust, the chemical composition and physical properties shows similarity to chemical composition and physical properties of earth's crust and hence these types of meteorites may also possibly be from the asteroidal belt. It is also possible that Chelyabinsk like meteorites may be of cometic material, because comets leave their debris on their path around the sun, while crossing each planets orbit. But comets are composed of Carbon (C) and Silicon (Si)[18], and possibly very negligible percentage of Iron (Fe). Hence Chelyabinsk like meteorites cannot be of cometic material, but may be a fragment of a bigger asteroid existing in the asteroidal belt. Therefore the source and origin of stony (rocky) nature of meteorites must also lie in the asteroid belt.

 

If considered that the asteroidal belt components are the fragments of a broken planet, then the leftover debris of terrestrial planets during their formation, where were they flung or thrown, is unknown, hence it has to be considered that the components lying in the asteroidal belt are leftover debris of terrestrial planets of our solar system and not the debris of a broken planet. Almost all the meteorites fallen on earth from time immemorial seems to come from asteroidal belt, which lie between Mars and Jupiter. They show similarity to terrestrial planets and hence their place of origin can be postulated to be in the asteroidal belt. Otherwise there is no reason to show similarity to terrestrial planets in chemical compositions and density.

The asteroidal belt contains millions fragments of rocks of different shapes and sizes, which reflects the core, mantle and crust of terrestrial planets, it seems that they may be the leftover debris of terrestrial planets which segregated at a particular place at the time the planets were formed. The rings pattern encircling the gas giants containing dust, small fragments of rocks of different shapes and sizes, postulated to be nothing but the leftover debris of respective planets formed during the formation of their parent body. Jupiter, Uranus and Neptune has thin rings pattern, whereas Saturn has a thick ring pattern which is clearly visible from a small telescope. The ring pattern of gas giants is a peculiar feature. Another prominent feature of these gas giants is the number of moons encircling their parent body. Why the leftover debris of terrestrial planets segregated at a particular place at the boundary which is known as asteroidal belt and why the leftover debris of gas giants are found to be encircling their parent body is not yet understood.

From the above studies, in short these three types of meteorites reflect the components of terrestrial planets in chemical and physical properties and hence their place of origin must lie in the asteroidal belt because all the three classes of meteorites i.e., stony (rocky), stony iron and iron represents the crust, mantle and core of terrestrial planets in every respect.

## 3. CONCLUSION

From the physical properties, chemical compositions, the observations of images in the figures and the results and discussions, the conclusion drawn from these studies is:

(a) The samples under study are genuine meteorites.
(b) The source and origin of iron nature of meteorites lies in the asteroidal belt, in other words it can be said that the asteroidal belt components are the store house of iron nature of meteorites as these fragments represents the core of terrestrial planets as per the studies conducted through this paper.
(c) The source and origin of stony iron nature of meteorites also lies in the asteroidal belt as they represent the mantle part of terrestrial planets, in other words it can be said that the asteroidal belt is the store house of iron nature and stony iron nature of meteorites.
(d) The source and origin of chondritic stony nature of meteorites can be inferred to lie either in the Oort cloud (where the source and origin of comets lie), Kuiper belt or interstellar space, where the dust or debris of Interstellar dust particles exist. This is inferred through the studies carried out through this paper.
(e) The source and origin of stony (rocky) nature of meteorites can be inferred to be from the asteroidal belt (because they represent the crust of terrestrial planets).

Meteorites so far found on earth represents their place of origin and environment in which they existed. Meteorites i.e., seteorites show the same elemental and chemical compositions which vary from metals (Fe, Ni, Co, Al. etc.,) to non metals (Si, Ca, Mg etc.,) and their oxides. These are the same elements commonly found in our solar system, but uniteorites has no specific chemical composition and no physical samples available on earth. Due to this the authors felt necessary to classify the meteorites into seteorites and uniteorites.

The studies conducted through this paper was a small effort to search, understand and confine the source and origin of meteorites fallen on earth, considering all the possible sources for the origin of meteorites of all the classes, which has been discussed in detail through this paper. Finally in short it can be stated that all the components existing in the solar system originated from one big source and that is either from solar nebula, Supernova explosion or Interstellar Dust Particles.

Meteorites are a source of valuable information about our solar system's initial stage, Or of earlier solar system? How were the sun and the planets formed? Or what are they exactly fragments of? What components exactly kindled the fire of life on earth? Was cometic material responsible? Or was Interstellar dust particles responsible? Or what was responsible? How was the distribution of the leftover debris spread in the solar system? Or beyond?

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**APPENDIX**


Fig. 1 Sikhote Alin iron meteorite


Fig. 2 Campo-del-Cielo iron meteorite


Fig. 3 North West Africa, stony (chondrite) Meteorite


Fig. 4 Nantan (China) stony iron meteorite

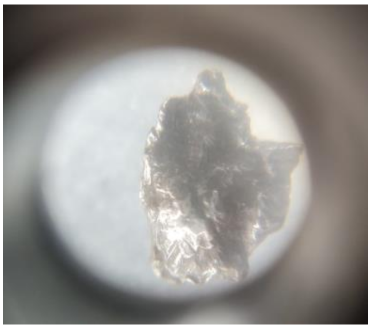
Fig. 5 Sikhote Aline iron meteorite observed through student microscope of 20x

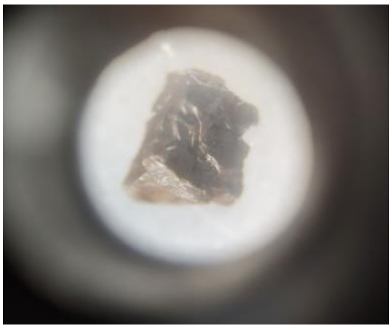
Fig. 6 Campo-del-Cielo iron meteorite observed through student microscope of 20x

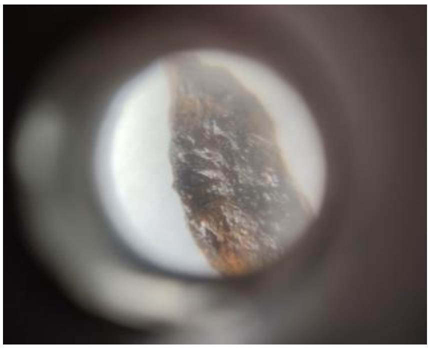
Fig. 7. Nantan stony iron meteorite observed through student microscope of 20x. The burnt part is clearly seen.

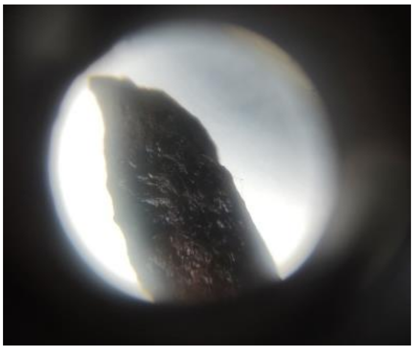
Fig. 8 Nantan stony iron meteorite observed through student microscope of 20x. The burnt and the rusting part is clearly seen

 

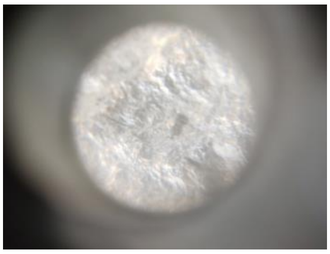

Fig. 9

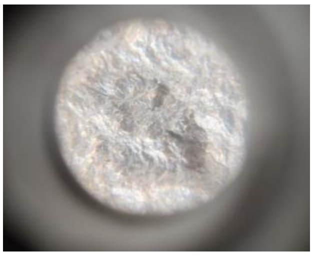

Fig. 10

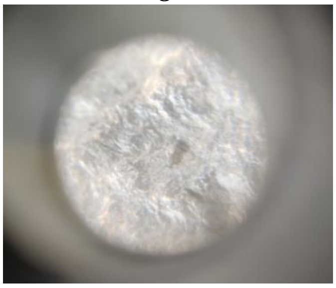

Fig. 11

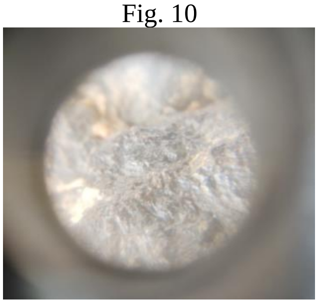

Fig. 12

Fig. 9, 10, 11 and 12: North West Africa (chondrite) type meteorites observed through student microscope of 20x. The surface features show components which resembles particles similar to chondrules.

Fig. 13. Stony iron meteorite Morocco.

**Table 1. Physical features of stony iron, stony and iron meteorites**

| Sr. No. | Meteorites | Colour | Lustre | Shape | Class | Dimensions in cms | Wt in gms | Density g/cc |
|---|---|---|---|---|---|---|---|---|
| 1 | Stony iron nature | | | | | | | |
| | (i) Nantan | Brown | Earthy | Elongated tapered | Stony iron | 1.1 x 0.3 x 0.2 | 1.2359 | 4.9436 |
| | (ii) Morocco | Brown | Earthy | Irregular | Stony iron | 1.6 x 0.9 x 1.0 | 3.43 | 3.43 |
| 2 | Stony nature | | | | | | | |
| | (i) North West Africa | Chocolate brown | Earthy | Irregular | Stony | 2.5 x 2.6 x 1.0 | 22.1922 | 4.43844 |
| 3 | Iron nature | | | | | | | |
| | (i) Sikhote Alin | Silvery shiny | Shiny metallic | Irregular | Iron | 0.6 x 0.4 x 0.1 | 1.5191 | 7.5955 |
| | (ii) Campo-del-cielo | Silvery shiny | Shiny metallic | Irregular | Iron | 0.5 x 0.1 x 0.4 | 1.5816 | 7.908 |

 

**Table 2. Chemical Composition of Sikhote Alin iron meteorite by XRF.**

| Sr. No. | Components | Results | Units |
|---|---|---|---|
| 1 | Fe | 87.6 | mass % |
| 2 | Ni | 4.74 | mass % |
| 3 | Si | 4.16 | mass % |
| 4 | Al | 1.22 | mass % |
| 5 | Co | 0.973 | mass % |
| 6 | P | 0.688 | mass % |
| 7 | S | 0.344 | mass % |
| 8 | Ca | 0.152 | mass % |
| 9 | Cu | 0.0973 | mass % |
| 10 | Sr | 0.0061 | mass % |
| 11 | Cr | -0.0037 | mass % |
| | Total | 99.9767 | mass % |

**Table 3 Chemical Composition of Campo-del-cielo iron meteorite by XRF**

| Sr. No. | Component | Results | Units |
|---|---|---|---|
| 1 | Fe | 90.8 | Mass % |
| 2 | Ni | 5.91 | Mass % |
| 3 | Co | 0.984 | Mass % |
| 4 | Si | 0.717 | Mass % |
| 5 | P | 0.699 | Mass % |
| 6 | Al | 0.433 | Mass % |
| 7 | Cl | 0.211 | Mass % |
| 8 | S | 0.144 | Mass % |
| 9 | Ca | 0.035 | Mass % |
| 10 | Cr | 0.0232 | Mass % |
| 11 | Br | 0.0057 | Mass % |
| 12 | Mo | 0.0052 | Mass % |
| 13 | Zr | 0.0037 | Mass % |
| | Total | 99.9708 | Mass % |

**Table 4. Chemical Composition of Nantan (stony iron) meteorite by XRF**

| Sr. No. | Element Code | At. No. | Formula | Element Name | Oxide Content | Mass % |
|---|---|---|---|---|---|---|
| 1 | Fe | 26 | $Fe_2O_3$ | Iron | 59 | 41.265 |
| 2 | Si | 14 | $SiO_2$ | Silicon | 28.7 | 13.415 |
| 3 | Al | 13 | $Al_2O_3$ | Aluminum | 8.44 | 4.467 |
| 4 | Ni | 28 | NiO | Nickel | 1.21 | 0.951 |
| 5 | P | 15 | $P_2O_5$ | Phosphorus | 0.956 | 0.417 |
| 6 | Co | 27 | $Co_2O_3$ | Cobalt | 0.402 | 0.286 |
| 7 | S | 16 | $SO_3$ | Sulfur | 0.368 | 0.147 |
| 8 | Ca | 20 | CaO | Calcium | 0.31 | 0.222 |
| 9 | Cl | 17 | Cl | Chlorine | 0.257 | 0.257 |
| 10 | K | 19 | $K_2O$ | Potassium | 0.192 | 0.159 |
| 11 | Ti | 22 | $TiO_2$ | Titanium | 0.116 | 0.069 |
| 12 | Zn | 30 | ZnO | Zinc | 0.026 | 0.021 |
| 13 | Cr | 24 | $Cr_2O_3$ | Chromium | 0.025 | 0.017 |
| 14 | O | 8 | | Oxygen | | 38.307 |
| | | | | Total | 100.002 | 100 |

 

**Table 5. Chemical composition of stony meteorite North West Africa by XRF.**

| Sr. No. | Element Code | At. No. | Formula | Element Name | Oxide content | Mass % |
|---|---|---|---|---|---|---|
| 1 | Si | 14 | $SiO_2$ | Silicon | 39.9 | 18.65 |
| 2 | Fe | 26 | $Fe_2O_3$ | Iron | 27.4 | 19.164 |
| 3 | Mg | 12 | MgO | Magnesium | 20.8 | 12.541 |
| 4 | Al | 13 | $Al_2O_3$ | Aluminum | 6.04 | 3.197 |
| 5 | Ca | 20 | CaO | Calcium | 2.34 | 1.672 |
| 6 | S | 16 | $SO_3$ | Sulfur | 1.61 | 0.645 |
| 7 | Ni | 28 | NiO | Nickel | 0.734 | 0.577 |
| 8 | P | 15 | $P_2O_5$ | Phosphorus | 0.488 | 0.213 |
| 9 | Cr | 24 | $Cr_2O_3$ | Chromium | 0.274 | 0.187 |
| 10 | K | 19 | $K_2O$ | Potassium | 0.178 | 0.148 |
| 11 | Cl | 17 | Cl | Chlorine | 0.12 | 0.12 |
| 12 | Mn | 25 | MnO | Manganese | 0.065 | 0.051 |
| 13 | Cu | 29 | CuO | Copper | 0.015 | 0.012 |
| 14 | Zn | 30 | ZnO | Zinc | 0.011 | 0.009 |
| 15 | Sr | 38 | SrO | Strontium | 0.011 | 0.009 |
| 16 | Ba | 56 | BaO | Barium | 0.011 | 0.01 |
| 17 | O | 8 | | Oxygen | | 42.795 |
| | | | | Total | 99.997 | 100 |

**Table 6. Chemical composition of Morocco (stony iron) meteorite by XRF.**

| Sr. No. | Component | Result | Unit |
|---|---|---|---|
| 1 | $Fe_2O_3$ | 45.7 | mass % |
| 2 | $SiO_2$ | 17.2 | mass % |
| 3 | CaO | 14.2 | mass % |
| 4 | MgO | 10.9 | mass % |
| 5 | $SO_3$ | 3.8 | mass % |
| 6 | $Al_2O_3$ | 2.93 | mass % |
| 7 | NiO | 2.42 | mass % |
| 8 | Cl | 1 | mass % |
| 9 | $P_2O_5$ | 0.877 | mass % |
| 10 | $Co_2O_3$ | 0.341 | mass % |
| 11 | $Cr_2O_3$ | 0.336 | mass % |
| 12 | MnO | 0.209 | mass % |
| 13 | CuO | 0.0197 | mass % |
| 14 | ZnO | 0.008 | mass % |
| 15 | $ZrO_2$ | 0.0065 | mass % |
| 16 | $MoO_3$ | 0.0054 | mass % |
| 17 | BaO | 0.0052 | mass % |
| 18 | SrO | 0.0028 | mass % |
| | Total | 99.9606 | mass % |

 

**Table 7. Difference between Nantan and Morocco (stony iron) meteorites.**

| Sr. No. | Component↓/Meteorite Name→ | Morocco | Nantan |
|---|---|---|---|
| 1 | $Fe_2O_3$ | 45.7 | 59 |
| 2 | $SiO_2$ | 17.2 | 28.7 |
| 3 | CaO | 14.2 | 0.31 |
| 4 | MgO | 10.9 | |
| 5 | $SO_3$ | 3.8 | 0.368 |
| 6 | $Al_2O_3$ | 2.93 | 8.44 |
| 7 | NiO | 2.42 | 1.21 |
| 8 | Cl | 1 | 0.257 |
| 9 | $P_2O_5$ | 0.877 | 0.956 |
| 10 | $Co_2O_3$ | 0.341 | 0.402 |
| 11 | $Cr_2O_3$ | 0.336 | 0.025 |
| 12 | MnO | 0.209 | |
| 13 | CuO | 0.0197 | |
| 14 | ZnO | 0.008 | 0.026 |
| 15 | $ZrO_2$ | 0.0065 | |
| 16 | $MoO_3$ | 0.0054 | |
| 17 | BaO | 0.0052 | |
| 18 | SrO | 0.0028 | |
| | $K_2O$ | 0.192 | |
| | $TiO_2$ | 0.116 | |
| Total | | 100.2686 | 99.694 |

**Table 8. Difference between Stony (rocky) meteorite and Stony (Chondrite) meteorite In Mass %.**

| Sr. No. | Oxides↓/Name of meteorites→ | Chelyabinsk (stony) meteorite | N.W.A. (Chondrite) stony meteorite |
|---|---|---|---|
| 1 | $Fe_2O_3$ | 46.4 | 27.4 |
| 2 | $SiO_2$ | 29.2 | 39.9 |
| 3 | MgO | 6.47 | 20.8 |
| 4 | $SO_3$ | 5.07 | 1.61 |
| 5 | $Al_2O_3$ | 3.8 | 6.04 |
| 6 | $P_2O_5$ | 2.88 | 0.488 |
| 7 | CaO | 2.07 | 2.34 |
| 8 | NiO | 1.39 | 0.734 |
| 9 | $Cr_2O_3$ | 1.2 | 0.274 |
| 10 | Cl | 0.785 | 0.12 |
| 11 | MnO | 0.445 | 0.065 |
| 12 | $TiO_2$ | 0.165 | |
| 13 | CuO | 0.0871 | 0.015 |
| 14 | $K_2O$ | | 0.178 |
| 15 | ZnO | | 0.011 |
| 16 | SrO | | 0.011 |
| 17 | BaO | | 0.011 |
| | Total | 99.9621 | 99.997 |