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# Reporting Mineralogy And Chemistry of Kamargaon Meteorite, Assam, NE India

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***Abstract:*** *We report here the composition and mineralogy of a meteorite, fell in Mahuramukh area near Kamargaon Town (93°46' E, 26°39'N;) of Golaghat District, Assam on November 13, 2015 at 12:00 hrs IST, weighing about 12.095 Kg, registered as KomarGaon Meteorite and reported in the Meteoritical Bulletin No. 104, 2016; classed as ordinary L6 meteorite. The meteoriteiscovered with encrustations of varied colourfusion crusts, thickness and occasional regmaglypts in its outer facewith radiating shock veins. The inner face is light greyish white studded with brown native metal. Thin section petrography, ore petrography and chemical studies were attempted using-state of the art analytical techniques such as EDXRF and SEM with EDS attachment. The chemical analyses were carried out on a representative piece of the meteorite sample. Mineralogically, the composition of meteorite is olivine, orthopyroxene, plagioclase and opaques. The ore petrographic study revealed opaque phases – consisting of pyrite, troilite, kamacite, taenite and millerite with minor amounts of magnetite. Olivine exhibits shock impact features of weaker to moderate intensity (S3 and S4), marked by development of planar fractures, encrusted with a mosaic of olivine and occasional occurrence of melt veins.*
*Chemically, the meteorite contains 21.99 %$Fe_2O_3$, and 20.25 % MgO; 35.97 % $SiO_2$; 4.02% $Al_2O_3$and Ni is about 0.32%. Due to the presence of merrillite and schreibersite, the $P_2O_5$content reads up to 735.719 ppm. SEM study reveals presence of Chondrules of chromite bearing magnetite, pyrite, Fe-Ni metals with widmanstatten texture.*

***Keywords:*** *Kamargaon Meteorite, ordinary chondrites, shock structures, mineral chemistry*

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## I. Introduction

Ordinary chondrites are believed to be the most primitive group of meteorites, formed at least 4.56 billion years before the present. The ordinary chondrite constitute about 85% of total recorded meteorites fallen on Earth. The origin of the tiny spherical structures, called 'chondrules', constituting of metal-rock composition is debatable matter.Studieson chondrites are useful in understanding the thermal processes involved in collusion of planetesimals. The compositions of chondrites are very similar to the composition of the Sun, except that they're lacking hydrogen and helium (Kerr, 2013). Chondrites bear spherical inclusions of minerals, called chondrules- a unique feature of chondritic meteorites. Every meteorite fall becomes an object of scientific study providing clues to the earths past history of over 4 billion years. The main objective of this paper is to report mineralogy and geochemistry of the meteorite fell in Mahuramukh area of Kamargaon Town (93°46' E; 26°39'N). The meteorite is registered as 'KomarGaon Meteorite';under the aegis of 'International MeteroitesSociety'; location-Golaghat District, Assam (NE India)onNovember 13, 2015 at about 12:00 hrs.(IST), weighing approximately 12 Kg (Fig. 1). The fall was on a soft ground, ploughed for sowing of mustard oil seed by the side of Gelabeel river bank. The Details of the meteoritefallwas initially reported by

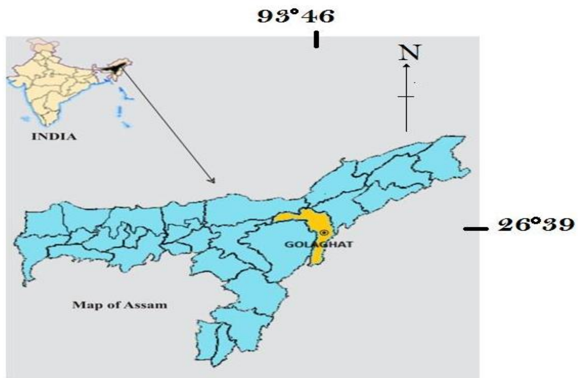


**Fig. 1**.Location map of the meteorite fall in Kamargaon Town of Golaghat district, Assam

Goswami et al., (2016). There has been another record of chondrite shower in Dergaon (93°52'E, 26°41'N) on March 02, 2001, in the neighbouring Golaghat area and in the south of Majuli island (93°46'48" E; 26°46'32"N) (Majumdar et al., 2004; Ray et al., 2016). Megascopic study revealed that the Kamargaon Meteorite resembles to a thin glossy ordinary chondrite, typically covered with fusion crusts of at least three generations. The older crust is smooth and dull brown with almost no regmaglypts while the youngest crust is black, contain glossy regmaglypts and marked with radiating fractures (Figs.2a and 2b) and shock metamorphism of type S3 and S4 (Stoffler et al., 1991). The distinction between different chondrites is made on the basis of chemical compositional changes in ferrous, total iron contents and in Fe/Ni ratios in the metallic components (Hutchison, 2004). Out of the three divisions of ordinary meteorites, e.g., H, L and LL groups (Urey and Craig, 1953), the 'Kamargaon' meteorite hasbeen classified as low Fe

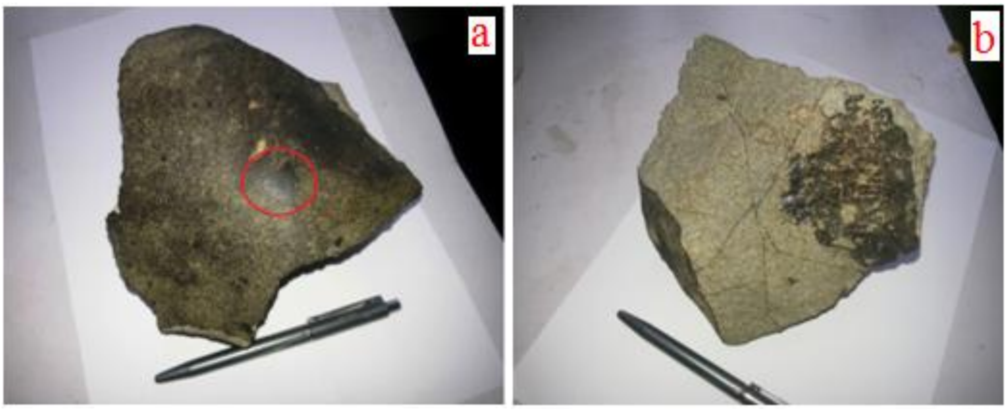


**Fig. 2**.Photographs of a piece of 'Kamargaon meteorite'. a. Visible specs of tiny circular grain (in mm dimensions), called 'chondrules' and indentations like imprints called 'regmaglypts' (marked by circle); b. 'Fusion crust' (black patch) with radiating impact fractures seen in the inner face of the meteorite.

bearingordinary chondrite of the class 'L'; since, the meteorite contains tiny chondrules, therefore, classified as ordinary L6 chondrite. Chondritic meteorites exhibit a range of Fe about 18-34 wt% and Mg about 8-16 wt%. Ordinary chondrites possess a decreasing trend of Fe from LL through L to H, although some scatter has been reported within these groups (Nittler et al., 2004).The presence of free iron in Kamargaon Meteorite imparts faint magnetic property to the studied meteorite. In this paperwe report the mineralogy, chemical composition and classification of the meteorite fallen in 'KamarGaon' utilizing tools like thin section petrography, ore petrography, scanning electron microscopy (SEM) and Energy Dispersive XRF (EDXRF).

## II. Methodology

Mineral characterization by SEM and EDXRF spectrometer studies were carried out at the Council of Scientific and Industrial Research-National Geophysical Research Institute (CSIR-NGRI) facility. SEM in particular, was done by Hitachi, S-3400N with energy dispersive spectrometry (EDS) as Spot analysis of different ore minerals and back scattered electron (BSE) imaging were carried out to understand the compositions and variations of different mineral phases. 15 kV accelerating voltage was used to get high resolution images from the meteorite samples. EDS spectra was obtained for one minute counting time with 15 kV accelerating voltage, number of counts obtained for individual analysis were depicted on the individual spectra

The EDXRF spectrometer (Epsilon 5; PAN analytical make was) used in the present study - equipped with a Sc⁄W anode X-ray tube with the goal of increased sensitivity for lighter as well as heavier elements. The instrument has a series of user selectable secondary targets and is equipped with a liquid-nitrogen-cooled Ge solid-state high-resolution detector with a Be (8lm) window. A 3-D design (or Cartesian geometry) was adopted for the instrument to eliminate the X-ray tube spectrum by polarization. Consequently, the background can be an order of magnitude lower than the traditional 2-D optics, resulting in much lower detection limits. The EDXRF used in the present study is equipped with a 100 kV Sc⁄W tube, even heavy rare earth elements (from Eu to Lu) can be analyzed using the more sensitive 'K' lines, and hence the instrument is less susceptible to spectral overlapping with the K lines of lighter elements.

Thin and polished sections have been studied in an Olympus Microscope using Stream Basic 1.9.4 storing and image processing software.

## III. Results And Discussion

### 3.1 Thin section petrography

Three nos. of thin sections were prepared one each from outer, middle and deep inner surfaces. The mineralogy does not change with respect to the position; however, the fusion intensity and shock magnitudes vary considerably. The mineralogy of the meteorite is olivine (40−42 vol.%), hypersthenes (25−28 vol.%) with occasional plagioclase (5–8 vol.%) and opaques (about 10 vol. %); compositions of olivine vary from forsterite to fayalite; plagioclase and orthoclase feldspars although rare but are recognizable under transmitted light microscope. The olivine shows planar fractures (Fig. 3a) in thin section drawn from inner face of the meteorite but its outer surface appears as mosaics of several splitted grains (Fig. 3b). Planar fracture and mosaicism in olivine are the result of shock metamorphism of the type S3 to S4 respectively (Stoffler et al., op. cit.). It is stated that shock melt veins in L6 chondrites contain high-pressure polymorphs of olivine and pyroxene and high pressure liquidus phases. The shock induced localized melting and formation of intrusive like melt dikes are commonly observed in the studied meteorite sample. Estimate show that an impact velocity 5 kms/s under a shock pressure <70 GPa produces a temperature about 900-1000$^{o}$C to form melt of about 0.05 to 0.1% metals (Kieffler and Simonds, 1980; Engelhardt and Graup, 1984). The opaque phases are affected by moderate to intense fracturing with shock melt veins. Fracturing of silicates, subsequent healing of micro-fractures by the metal melts often visible in the studied thin sections as has been envisaged by McSween et al., (1978).

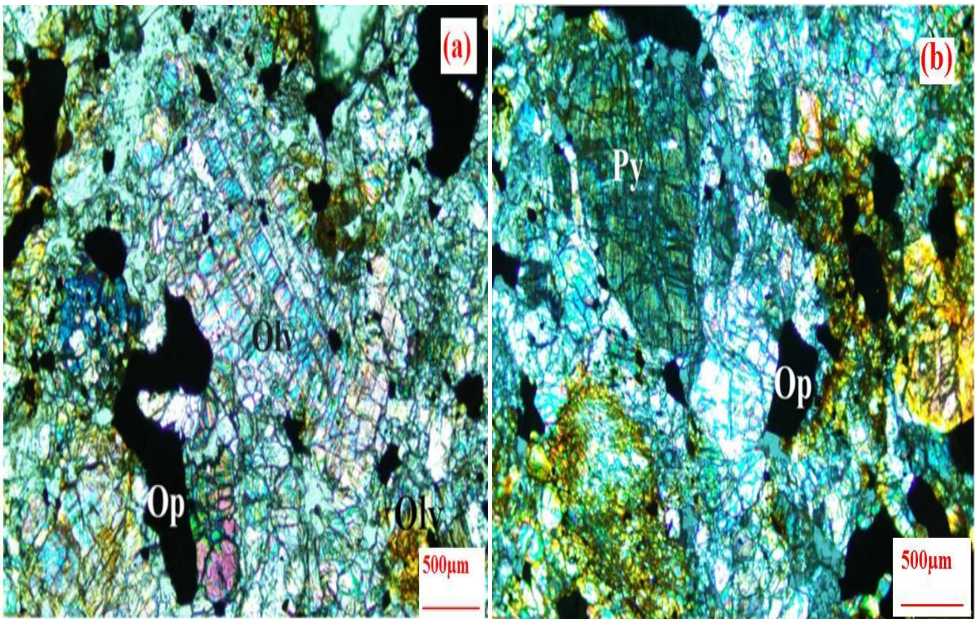


Fig. 3.Photomicrographs (thin sections) showing the mineralogical assemblage of olivine (olv), pyroxene (py) and opaques (op). a) olivines with planar fracture developed due to shock metamorphism (S3). b) pyroxenes (py) and mosaic of olivine grains formed due to shock metamorphism (S4).

### 3.2 Ore mineralogy

Optical properties under ore microscope apparently identify major ore minerals liketroilite, pyrite, millerite, and magnetite. Scanning Electron Microscopy (SEM) helps to confirm additional mineral phases apart from already identified by microscopic aid. Most of the Chondrules seen are with FeO (Magnetite with minor chromite) composition. The bright phases are Fe-Ni alloys, pyrite ($FeS_2$), troilite (FeS), schreibersite[$(Fe,Ni)_3P$], polycrystalline kamacite[Alpha-(Fe,Ni)] to composite grains of kamacite with dark etched plessiteandtaenite[gamma-(Fe,Ni)]. Optically, troilites are pinkish brown coloured, occur as anhedral or subhedral crystalline masses; often distinguished from whitish coloured pyrites; however, chalcopyrite remains unnoticed both under ore microscope and scanning electron microscope (Fig.4-7). Schreibersite appears as strings of beads forming worm and needle or tablet like inclusions, detectable by SEM (Fig. 5), inclusions in certain other ordinary meteorites. There are quench textures or Windmanstatten patterns, produced in high Ni octahedrites, revealed on etching the surface with dilute $HNO_3$.Widmanstatten patterns can only form over millions of years of cooling. The pattern actually tells how long it took for the molten meteorite to cool. The estimate is about 1000 years for a molten piece of planetary core to cool by just 1 degree Celsius.

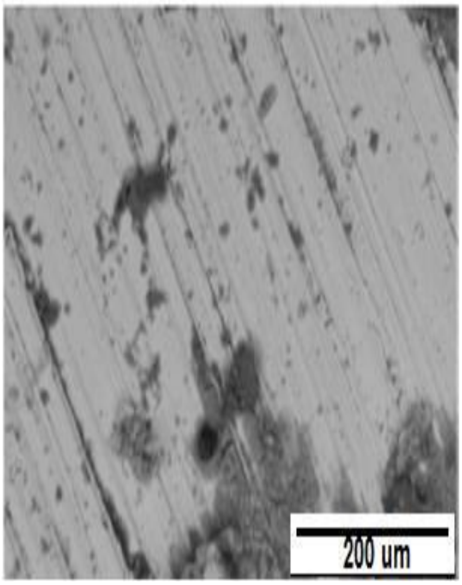


**Fig. 4**


**Fig.5**

Fig. 4.Unetched Fe-Ni metal with Windmstatten structures produced of high and low Ni rich bands.
Fig. 5.Schreibersite (sch) appears as strings of beads forming worm and needle or tablet like inclusions.

**3.3 Chemistry**

Chemical composition, determined by EDXRF of the studied Kamargaon meteorite is presented in Table 1. The meteorite is chemically possessing low iron (21.99 Wt. %) with about 20.25 wt. % MgO content; $P_2O_5$ is high (735.22 ppm), attributed by the phosphate minerals like merrillite$Ca_9NaMg(PO_4)$ and schreibersite[$(Fe,Ni)_3P$] with a nearly ideal chemical composition, $Ca_{9.00}Na_{0.98}(Mg_{0.95}Fe_{0.06})_{\sum 1.01}(P_{1.00}O_4)_7$, reported from the SuizhouMeteorite based on single crystal X-ray diffraction and Raman spectroscopy (Xie et al., 2015). The SuizhouMeteorite has been classified as shock-metamorphosed L6-chondrite similar to presently discussed KamargaonMeteorite. Chemical composition of the minerals identified is presented in Table 2. Mineral identifications have been made based on standard chemical composition such as Kamacite contains Ni about 7wt%; taenite having Ni value > 25 wt%. Recent studies show that ordinary chondrites contain chromite in trace quantity (0.05-0.5wt%) but it is rare or absent in carbonaceous chondrites and in iron meteorites (Schmitz etal., 2001). It is argued that, chemically the L group is more oxidized and has the bulk Fe/Si ratio to lie within a factor of 2 which is much larger than that observed in other groups. The present observation suggest a Fe/Si value of 1.14.The following important observations on Kamargaon meteorite have been confirmed by the Centre for Meteorite Studies, Arizona State University (ASU): olivine Fa25.1+0.4, Fe/Mn= 48.4+ 3.2 wt%; low Ca pyroxene $Fs_{\mathbf{21.2+0.2}}$ $Wo_{\mathbf{1.4+0.2}}$ Fe/Mn= 30.0+1.8 wt%; high Ca pyroxene $Fs_{\mathbf{8.4+0.3}}$; $Wo_{\mathbf{44.5+0.4}}$; feldspar $An_{\mathbf{9.4+0.4}}$ $Or_{\mathbf{6.7+0.2}}$(courtesy, L. Garvie).

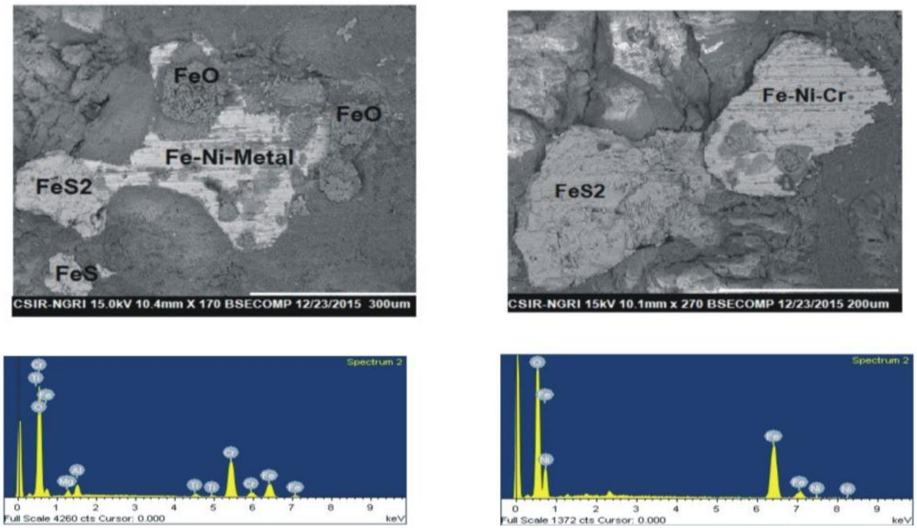


**Fig. 6**

Fig.6. Scanning Electron Microscopic images (SEM) of the meteorite section with spectra. Composite metallic composition (Fe-Ni-Cr), Pyrite (FeS2), Troilite (FeS), Magnetite (FeO) and troilite filled shock fractures with metallic shining in the upper part of first figure. Tiny chondrules are seen in SEM photogrphs. Spectral signature confirms the composion of the meteorite.

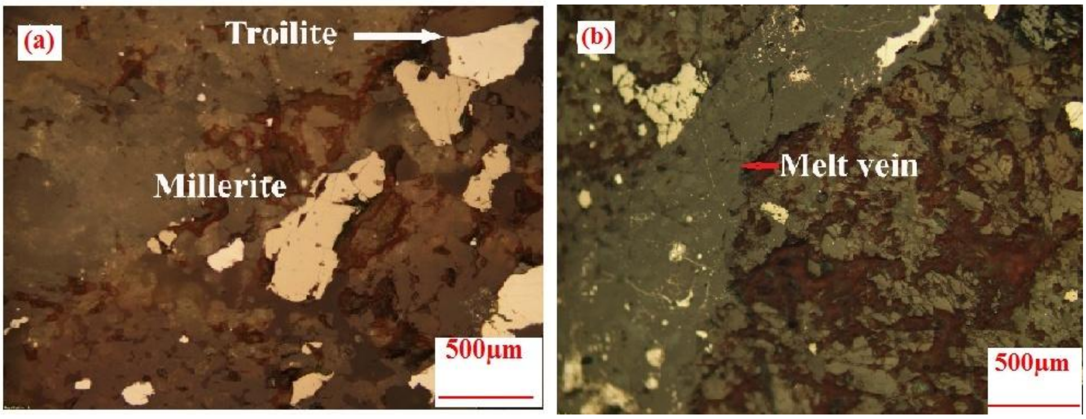


**Fig.7**. Photomicrographs of ore minerals with melt vein and disssseminated metals **a**) troilites (FeS) and millerites (NiS) in close association; **b)** melt vein with finely disseminated metals.

## IV. Conclusion

Based on mineralogical composition of olivine, pyroxenes and whole rock chemical composition, the Kamargaon meteorite has been classified as low iron ordinary L6 chondrite. Features of shock related metamorphism S3 to S4 have been anticipated based on the deformation pattern in olivine and production of shock melt etc. Exhibiting widmanstatten pattern by the Kamargaon meteorite is a unique feature in which lines and patterns narrates the cooling pattern of the meteorite in outer space over billion years.

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**Table 1:** Mineral chemistry of constituent minerals of KomarGaon Meteorite.

| Elements (wt %) | | | | | | | | | | Mineral |
|---|---|---|---|---|---|---|---|---|---|---|
| Fe | Ni | O | S | Si | Mg | Ca | Al | Ti | Cr | |
| 92.00 | 8.00 | - | - | - | - | - | - | - | - | Kamacite |
| 92.30 | 7.70 | - | - | - | - | - | - | - | - | |
| 92.14 | 7.86 | - | - | - | - | - | - | - | - | |
| 93.67 | 6.33 | - | - | - | - | - | - | - | - | |
| 95.49 | 4.51 | - | - | - | - | - | - | - | - | |
| 93.52 | 6.48 | - | - | - | - | - | - | - | - | |
| 88.53 | - | 5.08 | - | 4.19 | 2.19 | - | - | - | - | Magnetite(?) |
| 73.59 | 26.41 | - | - | - | - | - | - | - | - | Taenite |
| 63.02 | 14.01 | 22.97 | - | - | - | - | - | - | - | Alloys of Ni-Fe (meteoric iron) |
| 21.54 | 13.31 | 65.15 | - | - | - | - | - | - | - | |
| 18.98 | 13.76 | 67.26 | | - | - | - | - | - | - | |
| 37.40 | 1.22 | 61.38 | - | - | - | - | - | - | - | |
| 46.92 | 1.12 | 51.96 | - | - | - | - | - | - | - | |
| 52.27 | - | - | 47.73 | - | - | - | - | - | - | Troilite |
| 10.29 | - | - | - | 12.50 | 18.34 | - | - | - | - | Olivine |
| 2.80 | - | 62.70 | - | 18.50 | 15.33 | 0.61 | - | - | - | Pyroxene |
| 15.43 | - | 49.54 | - | - | 2.33 | - | 3.63 | 1.43 | 27.59 | Chromite |

Table 2: Bulk chemical composition of Meteorite ((EDXRF)

| Compound | Concentration | Unit | Compound | Concentration | Unit |
|---|---|---|---|---|---|
| $Na_2O$ | 1.393 | % | Ti | 501.72 | ppm |
| MgO | 20.25 | % | Cr | 0.32 | % |
| $Al_2O_3$ | 4.02 | % | Mn | 0.244 | % |
| $SiO_2$ | 35.97 | % | Fe2O3 | 21.99 | % |
| $P_2O_5$ | 735.72 | ppm | Ni | 0.32 | % |
| $SO_3$ | 5.51 | % | Cu | 53.03 | ppm |
| Cl | 392.15 | ppm | Zn | 55.01 | ppm |
| $K_2O$ | 1366.91 | ppm | Se | 6.90 | ppm |
| CaO | 1.72 | % | - | - | - |

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