GEOCHEMICAL EVIDENCE FOR THE METEORITE IMPACT ORIGIN OF RAMGARH STRUCTURE, INDIA.
S. Misra[1], G. Lashkari[2], D. Panda[3], A. Dube[1], M. S. Sisodia[2], H. E. Newsom[4] and D. Sengupta[1], [1]Dept. of Geology and Geophysics, Indian Institute of Technology, Kharagpur- 721 302, India (saumitramisra@yahoo.co.in); [2]Dept. of Geology, J. N. Vyas University, Jodhpur- 342 005, India; [3]Physical Research Laboratory, Ahmedabad- 380 009, India; [4]Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131, USA.

Introduction: The Ramgarh structure, Rajasthan, India (located at 25°20′N, 76°37′E) is a ring-like structure [1] that has an outer diameter of ~4 km and a rim height of ~250 m (Fig. 1) [2]. It was excavated on an extensive flat terrain of Neoproterozoic sandstone and shale of the Vindhyan Supergroup [3]. Many workers have proposed that this structure formed by impact [4-8]. Recently Sisodia et al. [2, 9] have reported PDFs in quartz in shocked sandstone under optical microscope from this crater. However the evidence in support of a meteorite impact origin is not yet conclusive [10].

Fig. 1. Perspective view of Ramgarh Crater looking north based on shuttle topographic data.

Occurrences of magnetic spherules within the clay in the outer part of the Ramgarh structure have been documented [6]. In the present paper we report for the first time microprobe data on the magnetic spherules recovered from inside this crater. The siderophile trace element chemistry of these samples and the presence of possible impact melt rocks, also favor a meteoritic impact origin for this crater.

Fig. 2. (a) An impact-melt looking material showing highly vesicular surface, length of sample ~5 cm, (b) A different sample of same type material showing ropy structures on surface, bar ~6.5 cm. Location: Ramgarh Crater, India.

Field evidence of impactites: We (S.M. and A.D.) conducted field work in 2007 and collected a few likely impact-melt rocks as well as magnetic spherules from the alluvium. One of these samples, collected from the western part of the crater is glassy, highly vesicular and shows vitreous luster (Fig. 2a). Another piece of glassy sample shows ropy structure on surface (Fig. 2b). Vesicular and ropy structures on surface in the rocks can develop due to the atmospheric airburst during small impacts [11].

The magnetic spherules analyzed for this investigation were collected from the soil inside the crater in one of our earlier field expeditions (by G.L. and M.S.) [2]. Our recent field work also identified the presence of these spherules outside of the crater within the finer fraction of reworked ejecta, particularly to the west, and also on the crater's southeast rim.

Analytical techniques: Microprobe analyses of ten selected spherules were carried out with a Cameca SX-100 machine at Physical Research Laboratory, Ahmedabad, India. All the analysis were undertaken at 15 KeV accelerating voltage, 15 amp sample current, and 10 micron beam size with PAP correction routine. Both the major and trace elements were analyzed together. The calibration standards used were Jadeite (Na), Peridot (Mg, Si), Kyanite (Al), Apatite (P), Pyrite (S), orthoclase (K), Wollastonite (Ca), Rutile (Ti), Chromium Oxide (Cr), Rhodonite (Mn), Almandine (Fe), Sphalerite (Zn) and metals like Ni, Co, Cu, Mo, Ba and Ge. Long peak counting times up to 50 seconds were used to reach detection limits of trace elements with low concentration.

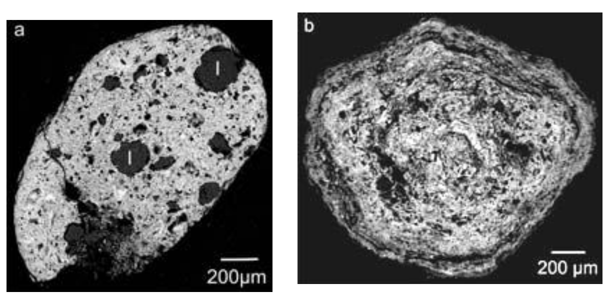

Fig. 3. BSE images of magnetic spherules from Ramgarh Crater: (a) grain without any internal structure, I- inclusions; (b) grain shows concentric growth rims.

Internal morphology of spherules: The magnetic spherules examined in this investigation can primarily be classified into two types based on their internal morphology (Fig. 3) viz., (a) grains that are homogeneous without any internal structure, and (b) grains with concentric growth rings. Note the inclusions of target rock sediments in the 'a' type of grains.

Geochemistry of Spherules: Average microprobe analyses (Table 1) show that the bulk composition of these spherules consists mostly of SiO_2, Al_2O_3, $Fe_2O_3^T$ and MnO in highly variable proportions. The relatively low average bulk total as seen here indicates presence of a considerable quantity of volatiles in these spherules. Trace elements of significant importance present in these spherules, in descending average proportions, are Ba, Co, Zn, Ni, S, Cu and Cr.

A bivariant plot of Ni versus Cr in most of the analyses shows a cluster of data between ~1200 ppm Ni and ~600 ppm Cr (Fig. 4a). An arguable positive correlation between these two elements can be seen. It is very important to note the amount of Ni, up to ~4000 ppm and Co up to ~7000 ppm with a positive correlation in these samples (Fig. 4b). Ni is abundant in various types of meteorites but occurs in very low concentration in the terrestrial rocks except for primary mantle-derived mafic and ultra-mafic magmas. The average Ni/Cr and Co/Cr ratios of these spherules are ~4 (0.06 to 32) and ~10 (0.06 to 58) respectively.

Table 1. Average chemistry of magnetic spherules from Ramgarh Crater, India. For major oxides number of analyses-94, for trace elements- 103. $Fe_2O_3^T$- total iron as ferric oxide.

	Average value	Minimum value	Maximum value
SiO_2	26.67	2.50	93.38
TiO_2	1.67	0.01	40.24
Al_2O_3	11.20	0.45	33.66
$Fe_2O_3^T$	34.40	0.96	83.37
MnO	4.36	0.00	29.66
MgO	1.42	0.06	5.91
CaO	1.96	0.09	11.92
Na_2O	0.58	0.01	7.50
K_2O	0.98	0.05	8.37
P_2O_5	0.27	0.00	0.87
Total	83.51	60.93	101.09
S (ppm)	376	30	1201
Cr (ppm)	172	0	1074
Co (ppm)	1088	0	7149
Ni (ppm)	523	0	3733
Cu (ppm)	303	0	5097
Zn (ppm)	741	0	11650
Ba (ppm)	5456	0	86967

Discussion: The target rocks at the Ramgarh Crater are mostly sandstone and shale. The shales when sampled with a magnet in the recent field expedition as well as in the laboratory were found to contain an insignificant amount of magnetic material. Limestone also sometimes occurs as host rocks at Ramgarh crater, which are also devoid of iron. The analysis of spherules from Ramgarh, however, shows a noteworthy, very high amount of iron. The evidence strongly suggests that the iron in the spherules is not a component of the target-rocks. At the same time the spherules have very high Ni, Co and Ni/Cr and Co/Cr ratios. These high ratios are suggestive of a meteorite component, but are exceptional in case of terrestrial rocks. These data, therefore, suggest an extra-terrestrial source for these elements and a meteorite impact origin of the Ramgarh Crater. The discovery of highly vesicular glass resembling impact-melt rock further supports the impact origin of the Ramgarh crater. A confirmatory study is in progress.

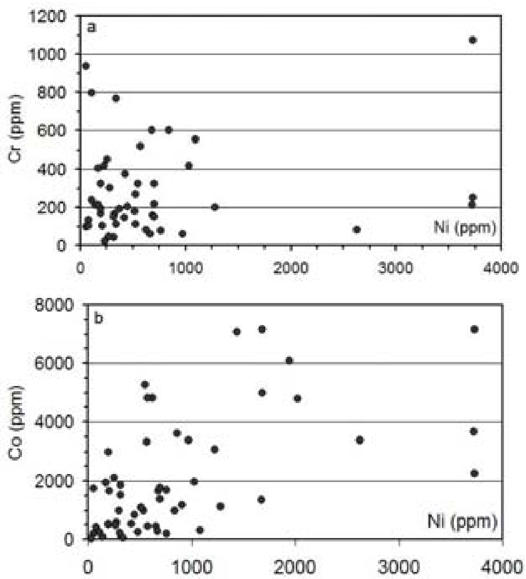

Fig. 4. Siderophile elements in magnetic spherules from Ramgarh Crater. Large concentrations of Ni and Co in many of the analyses indicates probable extra-terrestrial source, data as in table 1.

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