J. Ind. Geophys. Union (November 2016)
v.20, no.6, pp: 544-550

Microscopic Evidences for the Impact Origin of Ramgarh Structure, Rajasthan, India

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ABSTRACT
An impact crater on the Earth is a depression that is formed by the high velocity impact of an extraterrestrial object like meteorite. Impacts produced on Earth are highly exposed to obliteration by various geological agents. This demands the use of certain diagnostic criteria for the identification and confirmation of impact structures on Earth, the most important of these are crater morphology, geophysical anomalies, evidences for shock metamorphism and the presence of meteoritic material. Microscopic features like Planar deformation features (PDFs) and Planar fractures (PFs) in quartz grains are uniquely diagnostic of an impact event and are the robust evidences of the shock metamorphism due to an impact. A crater-like structure at Ramgarh, Rajasthan, India has been a contentious subject amongst the geoscientists for its origin. Evidences presented for the impact origin of Ramgarh structure so far are insufficient, equivocal and controversial. In this communication, we have reported the microscopic shock alteration evidences from the Ramgarh structure in the form of Planar Fractures and Planar Deformation Features in quartz grains.

Key words: Impact craters, Ramgarh structure, Shock Metamorphism and Planar Deformation Features.

INTRODUCTION

Studies by geologists on the impact structures led to an understanding that the collision of extra-terrestrial objects have significantly modified the Earth's surface, causing disturbances in its crust, and changed its geological history (Shoemaker 1977; Grieve, 1987, 1991; Nicolaysen and Reimold, 1990). However, Earth suffers from active erosion, volcanic resurfacing and tectonic activity, which tend to erase the impact features from the rock record. Therefore, the unambiguous identification of impact structures require their recognition based on certain diagnostic shock-metamorphic effects that are uniquely indicative of an impact (Grieve, 1991; Stöffler and Langenhorst, 1994; Grieve, 1998; Montanari and Koeberl, 2000; Koeberl, 2002; Langenhorst, 2002; Therriault et al., 2002). Shock-metamorphic effects have been critical to the identification of terrestrial impact structures because of their uniqueness and ease of identification. Ramgarh Structure in western India is a crater like feature impressed on the Neoproterozoic sediments of Vindhyan Supergroup. The origin of this spectacular feature has been a debated subject since its inception in the Geological literature and different workers have proposed their respective views towards its possible origin. Based on detailed geological mapping and structural analysis of the area, the structure was considered as a product of structural or tectonic deformation and named as Ramgarh Dome or oblong anticline (Prasad, 1984; Ramasamy, 1987). However, majority of the workers stand with meteoritic impact theory for its origin based on its near circular morphology, possible shatter cones, IRS-IA Image analysis, shear fracturing, granulation, anomalous birefringence in quartz grains, closely spaced-fractures and multiple-joint striated surfaces in quartzites, presence of Ni-Fe rich rounded micro glassy objects, glassy (microtektites) spherules, severely fractured quartz grains with corroded margins and microprobe analysis of magnetic spherules (Balasundaram and Dube, 1973; Crawford, 1972; Ahmad et al., 1974; Murali and Lulla, 1992; Master and Pandit,1999; Sisodia et al., 2008; Mishra et al., 2008). Though, Ramgarh structure closely resembles the other terrestrial impact craters, the evidences presented so far for its impact origin are scanty, equivocal, non-diagnostic and controversial. In the present paper, we have reported microscopic planar features in quartz grains resulted due shock metamorphism in the study area, an evidence supporting the impact origin of the Ramgarh structure.

Study Area

Ramgarh Structure (25º 20' N: 76º 37' E) is situated in Baran district of Rajasthan, 110 kms ENE of Kota city (Figure 1). The structure resembles Meteor crater of Arizona, USA in terms of shape and is obvious in topographic maps and satellite imageries (Sisodia et al., 2003) (Figure 2). This circular structure covers an area of 16 Sq.km with a diameter of about 4 km and rising about 250 m above the ground level. The Ramgarh structure is located in the central part of the Neoproterozoic Vindhyan basin of Rajasthan. On a regional scale the area in and around Ramgarh structure comprises the rocks belonging to Bhander Group of Vindhyan Supergroup (Ramasamy, 1987; Sharma, 1973) (Figure 3). The outer flanks of the

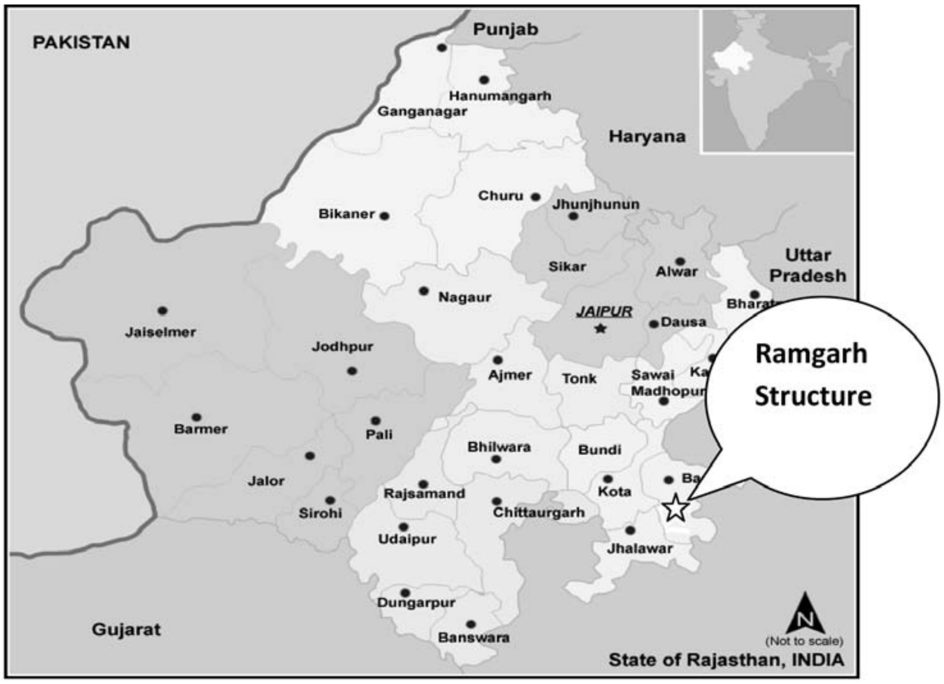

Figure 1. Location of Ramgarh structure (marked as Star) in the detailed map of the Rajasthan.

Figure 2. (**a**) Ramgarh Structure can be seen from a distance of 5-7 Km, (**b**) Google earth image of Ramgarh structure.

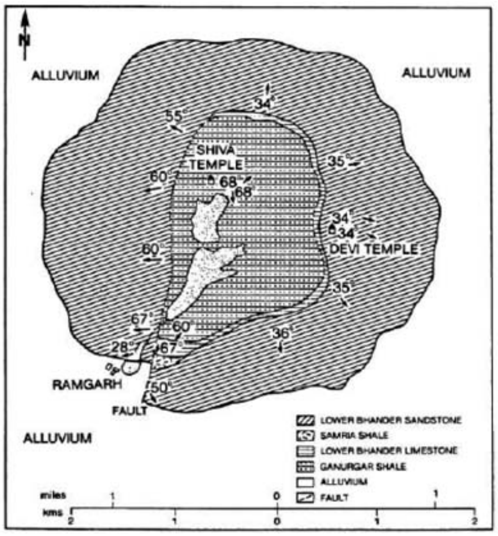

Figure 3. Geological map of Ramgarh Structure (Sharma, 1973).

Table 1. Shock-produced diagnostic deformation effects (after Montanari and Koeberl, 2000).

Pressure (GPa)	Features	Target Characteristics	Remarks
2-45	Shatter Cones	Best developed in homogeneous fine-grained,	Conical fracture surfaces with subordinate striations radiating from a focal point.
5-45	Planar Fractures (PFs) and Planar Deformation Features (PDFs)	found in many rock-forming minerals (e.g., quartz, feldspar, olivine and Zircon)	Sets of extremely straight, sharply defined parallel lamellae; may be in multiple sets with specific crystallographic orientations.
30-40	Diaplectic glass	Most important in quartz and feldspar (e.g., maskelynite from plagioclase)	Isotropization through solid-state transformation under preservation of crystal habit as well as primary defects and sometimes planar features
15-20	High-pressure Polymorphs	Quartz polymorphs most common: coesite, Stishovite.	Recognizable by crystal parameters, confirmed usually with XRD or NMR.
>15	Impact diamonds	From carbon (graphite) present in target rocks	Usually very small but occasionally up to mm-size; inherits graphite crystal shape.
45-70	Mineral Melts	Rock-forming minerals	Impact melts are either glassy (fusion glasses) or crystalline; of macroscopically homogeneous, but microscopically often heterogeneous composition.

rim are constituted of sandstone with quaquaversal dips. The inner flanks of the rim have relatively steeper slope (Sisodia et al., 2008).

METHODS

Circular geological structures of regional extent like that one present at Ramgarh, which is located in geological setting with no other probable mechanism for creating near-circular feature may be the result of a meteoritic impact and hence may be an impact crater. Only the presence of diagnostic shock metamorphic effects is considered as an unambiguous evidence for an impact event (Table 1). In complex craters, the central uplift usually consists of dense basement rocks and contains severely shocked material and this region should be examined in detail for the presence shock metamorphic signatures that confirm an impact event. This uplift is often more resistant to erosion than the remaining crater rocks, and thus possess the higher potential of preserving the shocked material (Grieve and Pilkington, 1996). In the present study diagnostic microscopic features in the form of planar Fractures (PFs) and Planar Deformation Features (PDFs) developed due to shock metamorphism are reported from the Ramgarh structure.

Shock waves are capable of generating a variety of unusual microscopic planar features in common rock forming minerals like quartz and feldspar. These features typically occur as sets of parallel deformation planes within individual crystals. The recognition and interpretation of these features, particularly those in quartz has played a crucial role in identifying new impact structures. Distinctive planar features in quartz have been one of the most widely applied criteria for recognizing impact structures (Engelhardt and Bertsch, 1969; Stöffler and Langenhorst, 1994; Grieve et al., 1996). Its abundance in crustal rocks, stability over long periods of geologic time, resistance to alteration by weathering makes it an ideal mineral for the same. It is an optically simple (uniaxial) mineral to study and to analyze on the Universal Stage.

Planar fractures are parallel sets of multiple planar cracks or cleavage like features in the quartz grain developed by the low level shock waves (< 10 GPa) which generally do not cross the grain boundaries. They are relatively widely spaced (> 5–20 μm) and thin (typically 3–10 μm), but thicker than PDFs (>20 μm). Planar deformation features (PDFs) are the distinctive and long-studied shock produced microstructures. These PFs, which appear identical to cleavage, occur typically in multiple sets, usually 2–3 sets per grain (French and Koeberl, 2010) (Figure 4). Extensive geological and experimental studies have established that these features develop at pressures of approximately 10–30 GPa, far higher than pressures produced by non-impact processes in crustal rocks.

In contrast to planar fractures, with which they may occur, PDFs are not open cracks. Instead, they occur as multiple sets of closed, extremely narrow, parallel planar regions. Individual PDFs are both narrow (typically <2–3 μm) and more closely spaced (typically 2–10 μm) than planar fractures (Engelhardt and Bertsch, 1969; Stoffler and Langenhorst, 1994; Langenhorst, 2002). Though, earlier workers have described Planar Deformation Fractures (PDFs) in quartz grains from the Ramgarh structure, but their authenticity is still doubtful.

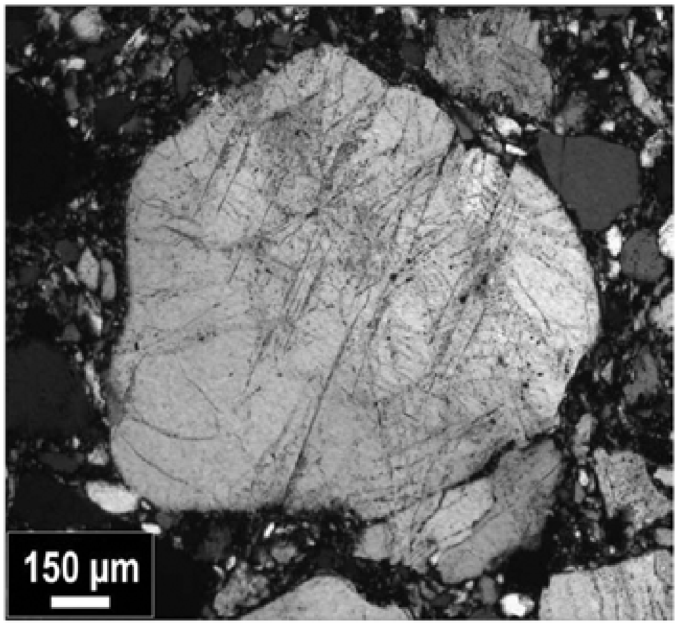

Figure 4. Planar fractures (PFs) developed in a brecciated quartzite from the central uplift of the Aorunga (Chad) impact structure. (French and Koeberl, 2010).

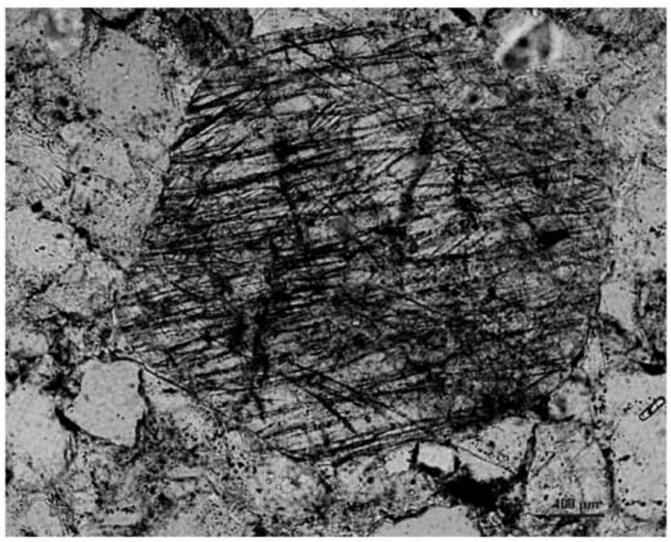

Figure 5. Photomicrograph of Planar fractures (PFs) developed in a quartz grain of sandstone from the central uplift of the Ramgarh Structure. Three sets of well-developed parallel narrow open fractures, filled with dark material (PPL View, 10X). Bar scale is 100μm.

Petrographic Studies

Petrographic observation of the sandstones collected from the centrally uplifted region by the authors have revealed the presence of shocked quartz grains marked by the significantly developed Planar fractures (PFs) as well as Planar Deformation Features (PDFs).

Seven thin sections of sandstones that were examined are showing shocked quartz grains with well-developed parallel set of narrow open fractures. Three sets of planar fractures have been noticed which are not crossing grain boundaries. These fractures are widely spaced (> 5–20 μm) and are oriented at specific angles to the c-axis of the host quartz (Figure 5). The planes consist of open fractures, filled with some dark material which may be ferruginous. The fractures are relatively thin (typically 3–10 μm), but relatively thicker than PDFs. The development of intense, widespread, and closely spaced planar fractures is strongly

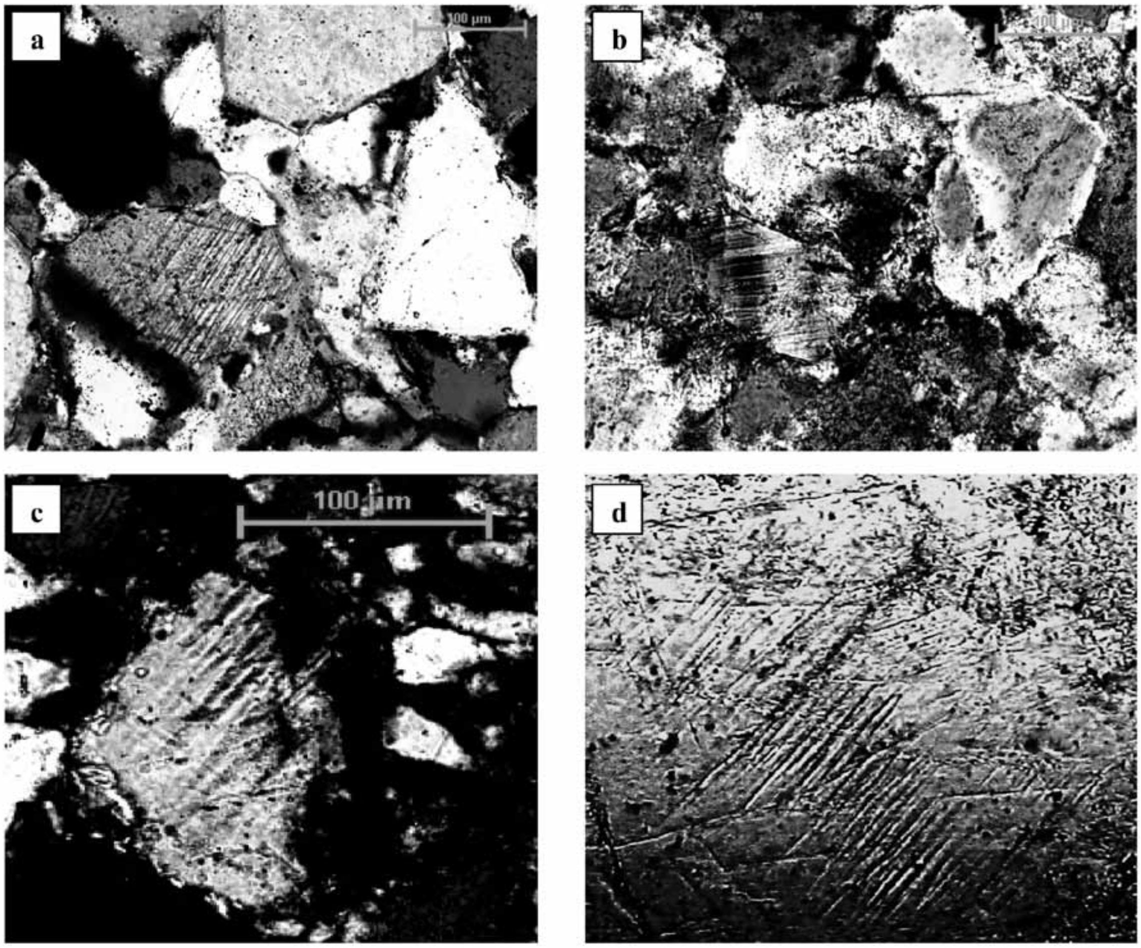

Figure 6. Photomicrographs of shock metamorphic features in quartz grains from Ramgarh Structure. (a) Decorated planar deformation features (PDFs) in a quartz grain from a sample of sandstone in the central uplift (crossed polarizers, 20X). (b) Planar deformation features in a large quartz grain (crossed polarizers, 20X). (c) Faint but obviously developed two sets of PDFs in another quartz grain (XPL, 20X); (d) Quartz grain with two sets of PDFs (PPL, 20X). The bar scale is 100 μm in all the photographs.

suggestive of shock, and such fractures are frequently accompanied in impact structures by other features clearly formed at higher shock pressures.

Several quartz grains (8-10 grains per thin section) with PDFs have been identified in the 10 thin sections of sandstones. The thickness of individual PDF lamellae is 1-3 μm, and the spacing between individual planes ranges from about 2 -5 μm. The PDFs are sharp, straight and confined within the grain boundary which are visible under high magnification in both plane polarised light and under crossed polars. Many of these PDFs are decorated with planar fluid inclusion trails (Figure 6a). In some quartz grains, PDFs are faintly developed but can be easily identified (Figure 6c). All the examined samples have revealed the presence of shocked quartz grains (10-12 grains per sections). These are recognizably distinct from endogenic planar micro deformation features or the Metamorphic Deformation Lamellae (MDLs) which are characterized by clearly irregular and non-planar character and lack of parallelism. Also MDLs are characteristically widely spaced then PDFs (>5μm).Since PDFs are characteristically produced in quartz under high shock pressures (>10GPa) and their occurrence along with Planar fractures at Ramgarh definitely indicate that PDF-containing Ramgarh sandstones have undergone intense shock metamorphism. However, the density of the PDFs in quartz grains of these sandstones is low because the porous sedimentary rocks respond differently to the shock waves. Shock waves passing through the porous sediments generate more heat mainly because more of the shock-wave energy is absorbed by the numerous grain interfaces and pore spaces in the sediment (Kieffer, 1971; Kieffer and Simonds, 1980; Stöffler, 1984). As a result, extensive melting will occur at lower shock pressures in sediments than in crystalline rocks Therefore, the density of quartz PDFs in shock altered sedimentary rocks like sandstones is very low, either because they did not form or because they were immediately destroyed by post shock melting.

CONCLUSIONS

During the course of present work detailed petrographic studies of the sandstones around the Ramgarh structure were carried out. Microscopic examination revealed the presence of Planar Fractures and Planar Deformation Features indicating shock metamorphism. Well-developed parallel set of narrow open fractures are noticed in the quartz grains exhibiting shock features. Owing to these diagnostic observations indicating shock metamorphism due to meteorite impact we infer an impact origin of Ramgarh structure.

ACKNOWLEDGEMENTS

This field study has been conducted as a part of BSR Fellowship funded by the UGC. Authors are thankful to Dr. G. Suresh, GSI, Hyderabad for his kind help in petrographic studies. Authors wish to record their deep sense of gratitude to Dr. Harsh Bhu, Professor and Head, Department of Geology, Mohanlal Sukhadia University, Udaipur, Rajasthan for helpful review of the manuscript. Sincere thanks are due to Shri Pawan Kumar Gautam, Geologist, GSI, Lucknow for his valuable suggestions in the preparation of manuscript. Constructive suggestions from the Editor of the Journal are gratefully acknowledged. Authors are grateful to Dr.V.V.Seshasai for constructive review and editing. We thank the Chief Editor for his support. At last, but not the least, we would also like to thank people at Ramgarh for their cooperation during the fieldwork.

Compliance with ethical standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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