DISCUSSION

IMPACT ORIGIN OF THE RAMGARH STRUCTURE, RAJASTHAN: SOME NEW EVIDENCES by M.S. Sisodia, G. Lashkari and N. Bhandari. Jour. Geol. Soc. India, v.67, 2006, pp.423-431.

W.U. Reimold[1], **C. Trepmann**[2] and **B. Simonson**[3], comment:

Sisodia et al. (2006), in their recent article on the origin of the Ramgarh structure, claim that they provide new evidence for an impact origin. We do not believe that any of the information presented in this article would sanction classification of Ramgarh as a proven impact structure. This does not mean that we negate the possibility that Ramgarh could be of impact origin, we only wish to make it clear that the evidence presented so far is not conclusive.

First of all, Sisodia et al. (2006) stress that the structure involves a "ratio of rock-exposure to rock-debris of 20% to 80%, indicating an uncommon geomorphological/geological feature denoting a sudden geological event...". This statement is not supported by any further information regarding the possible reasons of this high amount of rock debris. This could be the result of specific weathering and erosional conditions, including climatic conditions. More importantly, there is no information regarding time spans involved, in which case speaking of a "sudden" event appears unjustified.

The authors then proceed to compare some geological features observed at Ramgarh ("disharmonic folding and brecciation") with observations at large impact structures (Manicouagan and Charlevoix), but fail to point out that these same features are abundantly known from other, non-impact settings and, thus, do not necessarily have any impact-diagnostic value.

They also report "closely spaced fractures and multiple-striated joint surfaces, similar to those found at Sinamwenda Impact Crater". This observation suffers from several misconceptions. The term "multiple-striated joint surfaces" was coined by Nicolaysen and Reimold (1987, 1999) to describe sets of very closely spaced (generally <1 cm, often < 0.5 cm) joints of often curviplanar geometry that are invariably densely striated with striae resembling those on shatter cone surfaces. Nicolaysen and Reimold (*ibid*) inferred from their observations at Vredefort, and also Sudbury, that such closely spaced joints were related to the shatter cone phenomenon. Master et al. (1996) erroneously gave the same name to much more widely spaced joints, the geometries of which do not resemble Nicolaysen and Reimold's MSJS. Furthermore, no bona fide evidence for an impact origin for the 120 m Sinamwenda feature in Zimbabwe has ever been found. This demonstrates how hazardous it is, to rely on abstract information that lacks detailed descriptions. In any event, the features in Sisodia et al.'s (2006) Fig.4b do not resemble well-documented multiple-striated joint surfaces of impact origin and, thus, do not provide evidence in favour of an impact origin of Ramgarh.

These authors also report possible shock metamorphic deformation features. Specifically, they report that their samples contain "occasionally glassy material" and that, "many of the quartz grains are completely isotropic under crossed nicols. The margins of some grains are corroded possibly due to formation of high silica polymorphs...". This observation could be important, but it must be confirmed by additional analyses before these statements can be accepted as support for an impact origin. Neither the presence of glass nor of high-pressure polymorphs can be proven convincingly purely on the basis of optical petrographic observations. For example, XRD or Raman spectroscopic studies would be required to confirm the presence of high-pressure polymorphs.

Also the spherical objects they report do not support the impact interpretation of the Ramgarh structure, because the authors do not make a convincing case that they are microtektites and/or microkrystites. Although they superficially resemble such bodies externally, most well-documented impact spherules consist of transparent phases rather than iron oxides (Simonson and Glass, 2004 and references therein). Some of the spherules in figs.5f-h of Sisodia et al. (2006) contain crystals internally, but these are angular, equant crystals instead of the lath-shaped, acicular, and skeletal crystals commonly found in microkrystites, nor Do they show the circular outlines or

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composite infilling typical of in-filled vesicles (e.g., Smit, 1999; Simonson, 2003). Given their shapes and monocrystalline extinction, the crystals in the Ramgarh spherules are likely to be detrital inclusions. Their uniform distribution suggests the objects are more likely small iron oxide concretions than impact spherules, which is consistent with their roughly but not perfectly spherical shape (e.g., their fig.5d). An additional problem with an impact interpretation of these objects is their context. Although a few spherules have been reported from proximal ejecta such as the suevite breccia of the Ries Crater (Graup, 1981), the vast majority of impact spherules are found in distal ejecta layers far from craters. The latter are generally embedded in strata, whereas the Ramgarh spherules come from inside the potential source crater and appear to have been collected on the surface. The latter raises the possibility of contamination by spherules of a more exotic nature, e.g., fly ash.

Another line of evidence they cite is the presence of Ni in relatively high abundance compared to Fe. However, the ratio of nearly 1:1 Ni to Fe they cite is not typical of any known type of meteorites. For example, iron-nickel meteorites are differentiated into 17 groups, the Ni concentrations for which range between about 5 and 26 wt% but rarely ever approach 50% (Norton, 2002). Iron and Ni concentrations in chondrites also vary by more than an order of magnitude but again are almost always much less than 50%. In summary, the presence of Ni is intriguing and ought to precipitate further dedicated geochemical work, but high Ni values alone do not prove the presence of meteoritic material; a much more extensive chemical investigation is required to confirm or refute this possibility.

Sisodia et al. (2006) also report the presence of "diaplectic silica glass" and claim that "spherulites and mosaicism are features characteristic of a diaplectic glass". The latter simply is not true; diaplectic glass that is not recrystallised (e.g., via thermal overprinting after incorporation of a diaplectic glass fragment in hot impact breccia) is isotropic and characterised by a refractive index specific to the mineral from which it formed. However, as mosaicism in quartz forms between about 10 and 35 GPa and diaplectic quartz glass forms between about 30 and 50 GPa (Stöffler and Langenhorst, 1994; our own observations), it would be possible for quartz grains displaying both mosaicism and diaplectic quartz glass to occur in the same sample. It would also be possible, in principle, to observe grains that partially converted to diaplectic glass but still exhibit mosaicism in remnant crystalline areas, or remnants of crystalline quartz with PDFs in grains otherwise converted to diaplectic glass, as shock processes are characterised by extreme heterogeneity, even at the scale of individual grains. However, Sisodia et al. (2006) have not provided any proof for the presence of diaplectic quartz glass. The single photomicrograph provided shows an aggregate of fine crystals in an intriguing (chalcedonic?) texture, but they are clearly birefringent, which means the grains cannot be diaplectic glass.

Finally, these authors claim to have observed "PDFs" (planar deformation features) in Ramgarh quartz. PDFs are diagnostic of impact, but lines in their photomicrographs (figs. 7b-d) are more irregular, ill-defined and *non*-planar, unlike true PDFs (e.g., figures 4.16-4.23 in French, 1998). They appear instead to be similar to deformation bands more typical of tectonic deformation. Specifically, the features shown do not occur in sets of straight, sharply-defined features with closely-spaced traces that are typical for PDFs. In any event, the authors would need to determine the crystallographic orientations of their features to confirm their origin via shock and to verify their nature as true PDFs (Stöffler and Langenhorst, 1994). Moreover, optical microscopic observations may not be sufficient and TEM work might be necessary in order to establish that these lamellae are, composed of amorphous silica", as the authors claim.

Many recent publications have suffered from the problem of misidentification of PDFs (planar deformation features). PDFs are only produced at shock pressures in excess of about 8 GPa. Much of the volume of an impact structure does not attain such shock pressures – and no characteristic shock effects have been identified for the lower shock pressure regime. There are reports that "planar fractures in quartz are consistent with weak (<10 GPa) impact-induced shock" (e.g., Haines, 2005), but no proof for this has ever been published. Planar shock fractures (so-called PFs) have, however, been widely reported from quartz that also contains PDFs – thus demonstrating that PFs may well require shock pressures higher than 8 GPa. Neither comprehensive study of natural mineral deformation in weakly shocked rock from proven impact structures nor experimental calibration of this has ever been published. Especially in some small impact structures where no central uplift has been produced and sampling is restricted to rim sections, has it proven difficult to find minerals displaying the traditional shock-diagnostic deformation effects.

Based on our reading of the data put forth by Sisodia et al. (2006), we disagree with their conclusion that there are unambiguous evidences for an impact origin of the Ramgarh structure". We reiterate that this does not disprove an impact origin for the Ramghar structure; we simply believe that the authors need to pay closer heed to the well-established criteria for impact-generated and especially shocked materials that have been developed over more than 50 years of impact research We applaud the authors for their efforts to determine the origin of the Ramghar structure and hope they will undertake more detailed analyses such as those we have suggested If there are quartzose rocks in the central part of the crater such as sandstone or siltstone, they are probably the best target for further attempts to identify shock metamorphic evidence Such rocks are most likely to contain minerals well suited to preserve evidence of shock deformation, e g , zircon crystals and quartz, and will be located in the zone of this relatively small crater structure that would have experienced sufficiently high shock pressures to generate diagnostic impact effects

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Reimold et al (2006) point out some difficulties in our interpretation of various shock metamorphic features we have observed in rocks and minerals of the Ramgarh structure as evidences favouring its impact origin Whereas there may be some misconceptions and controversies in literature on which we have based some points of our discussion, the new observation of planar microstructures (Planar Fractures and Planar Deformation Features) in quartz grains that we have documented in our continuing study, as described below, further strengthens the main conclusion of our paper favouring shock origin of Ramgarh crater

Planar deformation features (PDFs) best develop in crystalline, non-porous rocks In porous rocks such as sandstones and shales, which is the host rock of Ramgarh structure, the shock wave energy gets largely dissipated and consequently formation of well-developed PDFs is rare (*see* Keiffer et al 1976, Koeberl et al 1998, French, 1998) However, a careful observation of sandstones at the Ramgarh crater rim and center has revealed easily identifiable planar fractures and PDFs Some of these are shown in Fig 1 Most of the fractures, invariably cleavage fractures, occur as deformation planes parallel to crystallographic planes (Fig 1a) Often around these planes brown to pink coloured, nonpleochroic, and few microns sized grains, called toasted quartz are concentrated Most of the fractures are healed and occur as fluid inclusion trails (Fig 1b) Many of the quartz grains in higher magnification show regularly spaced and extremely narrow PDFs and/or planar or sub-planar fluid inclusion trails in single or intersecting multiple sets (Fig 1c,d) The PDFs and fluid inclusion trails individually are both narrow, 1-3μm, and closely spaced, 2-30μm, typical of shock induced defects Some of the quartz grains illustrate dusty texture due to comminution (Fig 1e) Strings of small, high relief crystals, that petrographically look like high-pressure silica polymorphs (*see* Chao et al 1960), are also observed (Fig 1f) Feldspar grains, observed occasionally, also display planar microstructures (Fig 1g)

It is to be noted that in geologically old or metamorphosed rocks the original amorphous material in the PDF planes is recrystallized back to quartz Due to recrystallization strings of small fluid inclusions called 'decorations' develop along the original planes The resultant textures are called 'decorated PDFs' (Robertson et al 1968, Stoffler and Langenhorst, 1994) It can, therefore, be inferred that the above described fluid inclusion trails in the quartz grains are actually decorated PDFs, the ghost traces of original PDFs are still visible in some of the grains (Fig 1d)

In summary the common microscopic shock metamorphic effects observed in the quartz grains at Ramgarh Structure include (i) Planar fractures along crystallographic planes (ii) Irregular extinction and mosaicism (iii) Toasted quartz (iv) Isotropic grains and patches (v) PDFs and (vi) Decorated PDFs with occasional ghost traces of original PDFs These results collectively support impact origin of this enigmatic structure

Reimold et al disagree with our interpretation of anomalous rock-exposure rock debris ratio, fractures and multiple-striated joint surfaces, folding and brecciation in rocks and presence of iron bearing spherules as due to shock We agree that the joints in sandstone at Ramgarh crater are not as closely spaced as expected due to shock (see Nicolaysen and Reimold, 1999) and we have not found shatter cones either However, the spherules, particularly those, which are transparent and glassy, do not appear to us as concretions as claimed by Reimold et al , since they have no nucleus, generally found in concretionary spherules Some of these observations may not be as conclusive as PDFs indicative of intense shock

In conclusion, we would like to emphasize that the PDFs, as described above (Fig 1) cannot be produced in any terrestrial processes other than impact To the extent that quartz exhibiting planar deformation features is considered as an unambiguous evidence for shock metamorphism (e g , Alexopoulos et al 1988, Stoffler and Langenhorst, 1994, Huffman and Reimold, 1996), this observation substantiates the main conclusion of our paper, favouring impact origin of the Ramgarh Structure

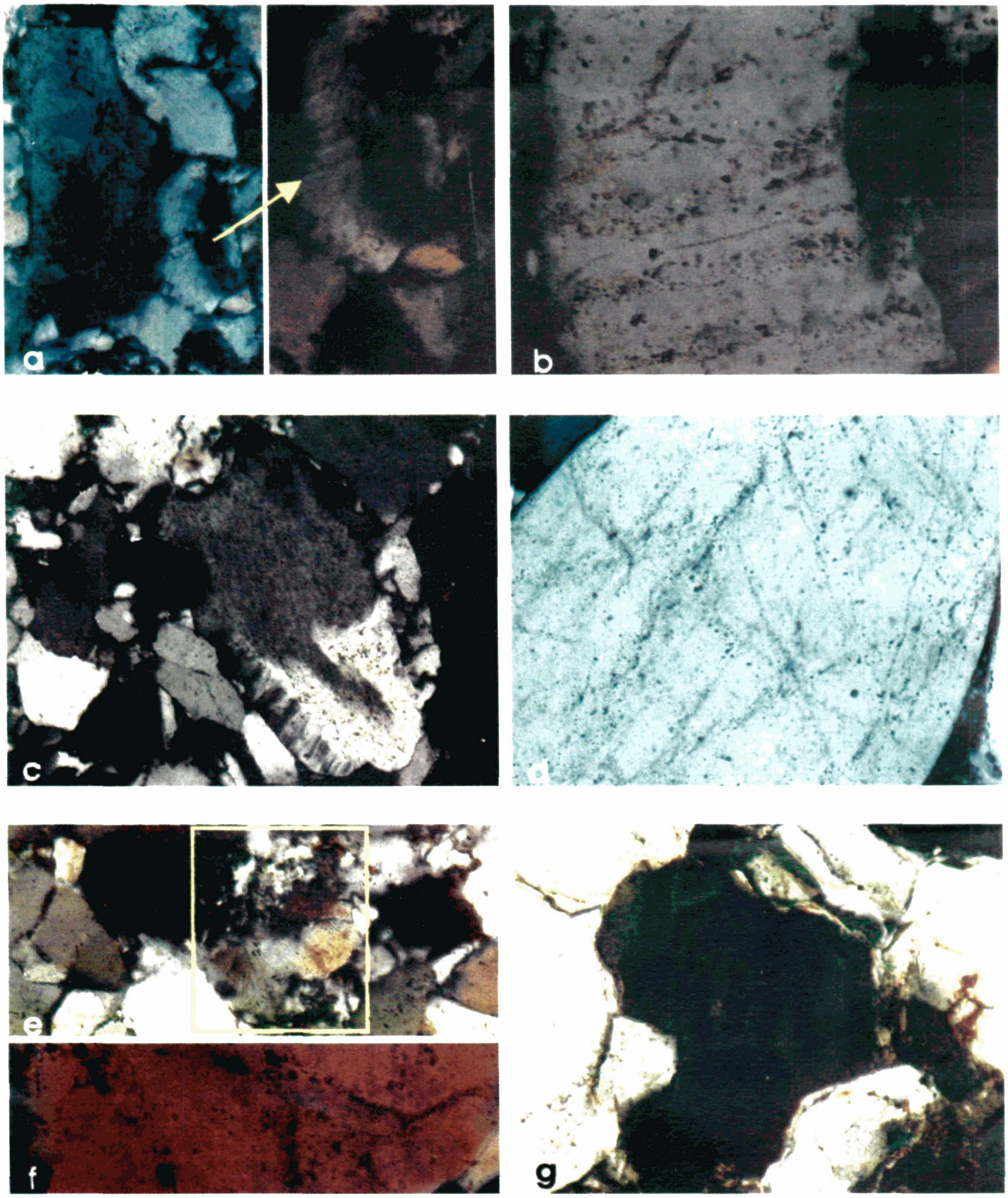

Fig.1. a. Shocked quartz grains: Quartz grain, in the left of the photograph, showing planar fractures; another quartz grain, in the right lower half of the photograph (shown in higher magnification also), showing intersecting multiple sets of PDFs, crossed polars, 200 µm wide. **b.** Quartz grain showing one set of sub planar fluid inclusion trails, crossed polars, 250 µm wide. **c.** and **d.** Shocked quartz grain displaying intersecting multiple sets of recrystallized PDFs (north/south; east/west; northwest/southeast; northeast/ southwest), the trails individually are both narrow 1-3 µm and closely spaced 2-30µm, numerous random larger fluid inclusions can also be observed scattered through the grain, crossed polars, **c.** 450 µm wide, **d.** 600 µm wide. **e.** Comminuted quartz grain, note: PDFs in the lower left and middle right of the grain while upper half of the grain shows dusty texture, crossed polars, 600 µm wide **f.** Strings of submicroscopic high relief crystals, crossed polars, 600 µm wide. **g.** Shocked feldspar grains showing recrystallized PDFs, note: the characteristic ladder structure, original polysynthetic twin lamellae are still preserved in the grains, crossed polars, 300 µm wide.

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NOTES

DIAMONDS IN OBDUCTED OCEANIC CRUST KIMBERLITES

At the 6th International Conference on the Geology of Middle East held during 20-22 March 2006 at Rotana Hotel, Al-Ain, UAE, S Nasir, A Alharthy, A A Al-Lazki and S Al Khirbash of Sultan Qaboos University, Sultanate of Oman reported the first record of allochthonous kimberlites and carbaonatites in Eastern Oman

The kimberlites and carbonatites crop out in the Batain plains of northeast Oman as tectonically transported Cretaceous age oceanic crust units that predate the Semail ophiolites These Group I kimberlites have been attributed to the mantle upwelling (ocean island) associated with the Reunion mantle plume

Discovery of these kimberlite-bearing tectonically transported oceanic lithosphere has significant implications for diamond exploration and may explain the presence of diamond either in kimberlite or alluvial deposits (glacially transported?) in continental regions that lack the thick lithospheric mantle

The author has attended the above conference and presented a paper on the Malani Supercontinent· The Middle East Connection during Late Proterozoic.

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