Mineral shock signatures in rocks from Dhala (Mohar) impact structure, Shivpuri district, Madhya Pradesh, India

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A concrete study combining optical microscopy, Raman spectroscopy and X-ray diffractometry, was carried out on subsurface samples of basement granite and melt breccia from Mohar (Dhala) impact structure, Shivpuri district, Madhya Pradesh, India. Optical microscopy reveals aberrations in the optical properties of quartz and feldspar in the form of planar deformation feature-like structures, lowered birefringence and mosaics in quartz, toasting, planar fractures and ladder texture in alkali feldspar and near-isotropism in bytownite. It also brings to light incidence of parisite, a radioactive rare mineral in shocked granite. Raman spectral pattern, peak positions, peak widths and multiplicity of peak groups of all minerals, suggest subtle structural/crystallographic deviations. XRD data further reveals minute deviations of unit cell parameters of quartz, alkali feldspar and plagioclase, with respect to standard α -quartz, high- and low albite and microcline. Reduced cell volumes in these minerals indicate compression due to pressure. The c_0/a_0 values indicate an inter-tetrahedral angle roughly between 120° and 144° , further pointing to a possible pressure maxima of around 12 GPa. The observed unit cell aberration of minerals may indicate an intermediate stage between crystalline and amorphous stages, thereby, signifying possible overprinting of decompression signatures over shock compression effects, from a shock recovery process.

Keywords. Dhala (Mohar) impact structure; shock signature; optical microscopy; Raman spectroscopy; X-ray diffractometry; parisite.

1. Introduction

The circular structure at Mohar ($25^\circ 18.228'$: $78^\circ 09.194'$; Survey of India toposheet no. 54 K/3), also known as Dhala impact structure, Shivpuri district, Madhya Pradesh, in the western part of Bundelkhand Gneissic Complex, was interpreted as a volcanic cauldron structure (Jain *et al.* 2001) and meteoritic impact crater structure (Pati *et al.* 2005, 2008), on the basis of absence or presence

of shock indicators, respectively, in the clasts of a rhyolite-like rock that crops out scantily around the structure. During the course of subsurface uranium exploration in this structure, the geoscientists of Atomic Minerals Directorate for Exploration and Research observed the presence of voluminous melt rock (melt breccia) beneath the mesa, which is the surface manifestation of the structure. Petrological study of drill core samples brought to light unequivocal and rampant evidences of

Figure 1. Geological map of Dhala structure, Shivpuri district, M.P. (modified after Bhattacharya 2006). On the right is the magnified part of the circular structure with bore hole locations.

shock metamorphic features in the melt breccia as well as the basement granitoids underlying it (Roy *et al.* 2014). The shock metamorphic features comprise planar deformation features (PDF)-like structures in quartz, feldspar, apatite and zircon, toasted, diaplectic, ladder-textured feldspars, selectively shock-melted feldspars, ballen quartz and melt-veined quartz. Pronounced aberrations were noted in the optical properties of common rock forming silicates in the form of discolouration of grains, development of fractures, lowering of birefringence resulting in anomalous interference colour, shock mosaics and isotropism of grains, melt veining, grain vesiculation besides pronounced deformation of grains. Recently, micro-Raman signatures of quartz and feldspars also revealed high degree of irregularities due to shock damage (Roy 2017). All this warranted mineralogical studies by various tools, in order to document shock deformation in rock forming minerals. In this paper, the optical-, micro-Raman spectroscopic- and X-ray diffractometry data on minerals are presented for the understanding of shock effect on rock forming minerals.

2. Geology

The Dhala (Mohar) circular structure (Dhala structure, Pati 2005, 2008; Mohar structure, Roy 2014) located in the western part of Bundelkhand Craton comprises mainly Archaean and Paleoproterozoic rocks referred to as Bundelkhand Gneissic Complex (BGC), unconformably overlain by the sediments of Meso- to Neoproterozoic Vindhyan Supergroup. The BGC is dominated by Bundelkhand granitoids together with minor enclaves of older metamorphic supracrustals comprising metasediments, metavolcanics, rocks of Tonalite–Trondjemite–Granodiorite (TTG) affinity, mafic and ultramafic rocks (Basu 1986; Mondal *et al.* 2002). It is traversed by quartz reefs and dolerite dyke swarms. The Dhala (Mohar) structure (figure 1) is noticeable due to the conspicuous presence of a 4.5 km diameter mesa of sedimentary rocks, protruding up by about 100 m, above a backdrop of concentric annular ring-like outcrops of sediments of Dhala Formation (pre-Kaimur) outwardly followed by prominent hummocky granite breccia (Jain *et al.* 2001; Pati *et al.* 2008; figure 2).

The lithology of the structure is established on the basis of extensive surface and subsurface studies, carried out by AMD, during the

Figure 2. The near-circular mesa-like structure. (K: Kaimur Group; D: Dhala Formation; GB: Granite breccia; QV: Quartz vein).

course of exploration. The lithologic succession comprises basement Bundelkhand granite overlain by melt breccia of variable thickness. This is unconformably overlain by shale-siltstone of Dhala Formation and sandstone of Kaimur Group (Vindhyan Super Group). The melt breccia, occurring as sparse isolated outcrops around the structure, is an extremely heterogeneous pink to brick red, vesicular to non-vesicular tuff-like rock, having an extremely variable thickness (up to about 200 m in the central part of the structure), below the sedimentary cap. Few pockets of it are also noted within the basement granite at depth, indicating that the melt pockets were formed at the time of impact. The disposition of different litho units within the structure can be envisaged from strip logs along E–W and N–S section across the structure (figure 3a, b). It is established from the subsurface data that the structure, with a 7.5 km diameter, is that of a simple crater without a central uplift, as no granitic basement rocks have been intercepted at shallow depths in any of the boreholes drilled at the center of the mesa. The basement granite as well as the melt breccia bear signatures of shock metamorphism, with the latter possibly having been derived by the shock melting of the former (Roy *et al.* 2014).

3. Methodology

Integrated study was carried out on borehole core samples from Dhala (Mohar) structure to understand the mineralogy of the basement granite and melt breccia, with the aid of optical

Figure 3. (a) Striplog (not to scale) of MC-2, MCB-22, MCB-28A, MCB-29, MC-1 and MCB-59 along E–W showing different lithounits in core column. (MC-1,2 were drilled by GSI; others by AMD), (b) Striplog (not to scale) of MCB-66, MCB-32, MCB-16, MCB-12 and MCB-14 along N–S showing different lithounits in core column. DD is drilled depth and V is vertical bore hole).

Figure 4. Striplogs (not to scale) of vertical bore holes MCB-16, MCB-29 and MCB-39 showing different lithounits in core column. Black arrow denotes depths of studied samples. DD is drilled depth.

microscopy, Micro Raman spectrography and X-ray diffractometry. The strip log of the boreholes, from which samples were studied are represented in figure 4. Optical microscopy was carried out under Nikon polarized light microscope. Micro Raman spectroscopy on selected minerals, was performed on uncovered thin sections of rock. The Horiba JY HR Lab Ram laser micro Raman spectrometer used for this purpose at Wadia Institute of Himalayan Geology, Dehradun, is fitted with 514.4 and 785 nm lasers, 600 and 1800 mm lines grating, multichannel CCD detector and confocal optics. The 514.4 nm exciting line of Spectra Physics Ar⁺ laser was focused on the samples through Olympus BX41 microscope with a laser beam diameter of <2 μm at 100× objective. Silicon standard was used in the calibration of the instrument and the spectral resolution of the instrument is 1–2 cm⁻¹. Data management is through Lab-Spec 5 software. X-ray diffractometry was carried out with the help of Siefert Id 3000-X-ray generator and Siemens microprocessor controlled D-500 diffractometer system, using crystal monochromated characteristic CuKα radiation and LA 100 recorder. X-ray diffraction (XRD) study on powdered whole rock samples was carried out in Siemens D-500 diffractometer. The accelerating voltage was maintained at 35 kV and the

tube current at 22 mA. CuKα radiation (1.5418 Å) was used and curved graphite constituted the monochromator. For identification, a scanning speed of 0.03 degrees 2θ/second, over a long angular range, with a sampling time of 2 sec, was selected. Mineral identification was done from the powder diffraction data obtained and matching the same with the relevant International Centre for Diffraction Data (ICDD) card.

4. Results

4.1 Optical microscopy

Optical microscopy and petrological study was carried out on samples from basement granite and melt breccia. The findings are discussed below.

4.1.1 Basement granite

It is generally shocked, with rusty red feldspar and chalky white opaque quartz in the bore hole cores (figure 5a) and is microscopically characterized by highly deformed feldspars (figure 5b) and a wide variety of shock metamorphic features that leave indelible marks on quartz, feldspar, biotite, zircon and apatite (Roy *et al.* 2014). The rock comprises medium grains of highly deformed, dark red, toasted feldspars, quartz with rampant

Figure 5. (a) View of core sample of shocked basement granite. Note contact with melt breccia at the top. (b) Deformed feldspar in shocked granite. Trans. Light, 1Nicol, air, bar=0.1 mm. (c) Accessory parasite with lamellae/striation in shocked granite (confirmed by Raman Spectroscopy), Trans. Light, 1Nicol, air, bar = 0.05 mm. (d) The same mineral under crossed Nicols. (e) View of core sample of melt breccia. (f) Chaotic assemblage of clasts, glass schlieren (dark brown) and felsic groundmass (red) constituting melt breccia. Trans. Light, 1Nicol, air, bar = 0.5 mm.

planar deformation features (PDF)-like structures, heterogeneous anisotropism or melt veining, biotite/chlorite showing kink banding and accessory zircon and apatite exhibiting planar deformation feature. The feldspar grains often exhibit lowered birefringence, anomalous interference colour, ladder textures and planar/non-planar fractures. Many feldspar grains are diaplectic and also show signs of vesiculation, core melting and centre-to-periphery plastic flowage, indicating conditions of extreme shock. Quartz grains are also marked by very low birefringence and highly undulose extinction, often exhibiting planar/non-planar, radiating fractures, in addition to PDF-like structures and in cases of extreme shock, develop reticulate melt veins. In addition to the rock forming minerals, an optically indeterminable transparent, subhedral, accessory mineral (figure 5c) is found to occur in clusters within the interstice of green biotite,

shocked quartz and toasted feldspar. This mineral is marked by conspicuous brown lamellae/striations, very high interference colour (figure 5d) in the transparent portion and gives very low density alpha tracks on CN-85 film exposed for seven days.

4.1.2 Melt breccia

This unit comprises of highly heterogeneous rocks containing varying proportion of green to red groundmass, clasts of rocks and minerals, as well as glass schlieren/fiamme, as observable in core samples (figure 5e). Both vesicular and non-vesicular varieties of melt rocks are present. The groundmass of the melt breccia is composed of red or green glassy material or microcrystalline feldspar aggregate and the latter composed of poorly sorted shocked/unshocked fragments of quartz, feldspar,

Figure 6. (a) Photomicrograph of quartz with PDF. Bar: 0.1 mm. (b) Corresponding Raman spectra in the right. (c) Photomicrograph of toasted K-feldspar. Bar: 0.1 mm. (d) Corresponding Raman spectra in the right. (e) Magnified photomicrograph of parisite showing striations, Trans. light, 1N, air. (f) Sparse alpha tracks (fine black dots) on CN-85 film to indicate weak radioactivity, Trans. light, 1N. (g and h) Magnified part of transparent part and dark striation respectively. Red is the probe spot, Trans. light, 1N. (i and j) Raman spectra of transparent part and dark striation.

granite rock fragments, basic rock fragments and glass schlieren (figure 5f). The groundmass often exhibits flow texture as it entrains randomly oriented fragments or primary vesicles along the flow. Occasionally, it contains evidence of carbonate–silicate melt immiscibility (Roy 2016). The shock

signatures in the fragments include PDF-like structure and mosaics in quartz, toasted and ladder-textured feldspars, near isotropised, diaplectic quartz and feldspars, grape-like Ballen quartz, kink-banded biotite/chlorite and shock isotropised bytownite bearing erstwhile altered mafic rock.

Figure 6. (Continued.)

4.2 Micro Raman spectroscopy

Micro Raman spectroscopic study was carried out on selected samples from basement granite and melt breccia. The minerals from basement granite includes quartz exhibiting multiple PDF-like structure and reddish brown toasted feldspar.

4.2.1 Basement granite

The spectra of quartz (with PDF-like structure), toasted feldspar and parisite (sample no. MCB-29/309.05) are shown in figure 6. The spectra of quartz with PDF (figure 6a, b) matches well with standard α -quartz (Raman shift peaks at 205, 464 cm⁻¹) and that of toasted feldspar (figure 6c, d) with standard orthoclase (Raman shift peak around 514 cm⁻¹ with prominent triplet between 450 and 515 cm⁻¹). However, minor aberration noted in case of quartz is that the standard peak of 800 cm⁻¹ is missing in the studied grain, whereas an extra peak is observed at 1300 cm⁻¹. In case of orthoclase, small additional peaks are observed around 1300 and 1500 cm⁻¹ in the studied grain. The optically indeterminable transparent subhedral mineral (figure 6e) that is weakly radioactive

(figure 6f) and occurs as accessory constituent in the shocked granite, is identified as Parisite (a fluorocarbonate of Ca and Ce), as per Raman spectral pattern. It is notable that the transparent part (figure 6g) and the brown striation (figure 6h) are characterised by spectra (figures 6i, j respectively) that do not show any noticeable difference, indicating a uniformity in composition, matching closely with that of standard parisite spectral pattern. However, the spectra deviates from the published data (mindat.org) in having a sharp drop of Raman shift from 300–400 cm⁻¹ and thereby deviated of a gentle peak at 400 cm⁻¹ as observed in the published data. An additional small peak is observed in the sample around 670 cm⁻¹. These may be due to lattice distortion attributable to shock damage.

4.2.2 Melt breccia

A pale green mafic fragment (3 mm across) embedded in a red felsic glassy groundmass of the melt breccia was the subject of analysis. The clast, under the naked eye (figure 7a; sample no. MCB-39/254.35) is composed of off-white fine lath shaped minerals associated with green altered

Figure 7. (a) View of scanned thin section of melt breccia. Mafic clast shown within frame. (b) Photomicrograph of part of mafic clast (MC) in melt breccia (MB). Trans. light, air, 1N. (c) Photomicrograph of shocked plagioclase laths (P) within mafic clast. Note dark colour under 1N. (d) Same photomicrograph showing inhomogeneity in back-lit view. (e) Same photomicrograph showing near isotropism under XN. (f) Raman spectra of analysed bytownite. Red frame highlights aberration from standard bytownite.

minerals. Microscopically, the mafic clast (figure 7b–e) is composed of dark brown partially isotropic to weakly anisotropic and non-uniformly birefringent laths. Optical identification of this mineral was difficult due to obliteration of primary optical properties. Micro Raman analysis of the mineral (figure 7f) characterised it as

bytownite (highly calcic plagioclase). It is notable that although standard spectrum of bytownite is broadly comparable with bytownite of the studied sample, there are noticeable aberrations, *viz.*, peak broadening around Raman shift of 700 cm^{-1} and development of a peak between 1200 and 1300 cm^{-1} .

4.3 X-ray diffractometry

The minerals identified by X-ray diffraction (XRD) method in the melt breccia as well as the shocked basement granite are quartz, albite, microcline, biotite, hornblende, chlorite, apart from traces of calcite, galena, sphalerite and chalcopryrite. The crystallographic parameters of quartz and feldspars of a few samples are presented in table 1.

It is noted that a_0, c_0 and cell volume of the analyzed quartz from shocked granite, are close to that of α -quartz (a_0 is less than and c_0 is comparable or slightly greater than that of α -quartz). In melt breccia, however, a_0 of quartz is greater than and c_0 and cell volume are lesser than that of α -quartz. The c_0/a_0 ratio ($n=4$) in the shocked granite varies from 1.0996 to 1.1004 and the cell volume varies between 112.9071 and 112.9431 Å³, being clearly less than that of α -quartz. For α -quartz, the silica tetrahedral structure are strictly regular (Si–O–Si angle of quartz is $\sim 144^\circ$) if c_0/a_0 is < 1.098 . This ratio increases with pressure and when c_0/a_0 becomes > 1.14 the inter-tetrahedral angle decreases to $< 120^\circ$ (Deer *et al.* 2004). This indicates that (i) the silica tetrahedral structure in the present case is not strictly regular and (ii) with c_0/a_0 ratio ranging 1.0996–1.1004 (with error ranging between $\pm 2 \times 10^{-6}$ and $\pm 55 \times 10^{-6}$), the inter-tetrahedral angle lies between 120° and 144° . From the comparison of c_0/a_0 with pressure worked out by Angel *et al.* (1997), high pressure experimental data on gem-quality single crystals of twin-free natural quartz), which documents pressure variation with c_0/a_0 , the four sample points (MCB 16/266.02, 376.90, 379.11; MCB 29/309.25) cluster near c_0/a_0 values of 1.1 (figure 8). But this does not apparently corroborate the optical presence of PDF-like structures in quartz which is believed to be formed at pressures 8–25 GPa (French 1998). Thus, there is some mechanism that is instrumental in the formation of PDF-like structures in quartz, but subsequently erasing all other signatures associated with the shock load that caused the PDFs to appear. Kingma *et al.* (1993), using *in situ* X-ray diffraction, Raman scattering and optical microscopy, studied α -quartz at high pressure and found that a new phase transformation occurs at 21 GPa, which on decompression, reverts to a quartz-like structure which is now in the form of a mixture of crystals with an increasing proportion of amorphous silica, as the pressure increases beyond 21 GPa. This may explain why quartz grains that bear PDF-like

Table 1. Unit cell parameter of minerals from basement granite, as determined by XRD technique.

Mineral	a_0 (Å)	b_0 (Å)	c_0 (Å)	$V(\text{Å}^3)$	α	β	γ
MCB-29/309.25 (shocked basement granitoid)							
Quartz	4.9121 ± 0.0001		5.450 ± 0.0001	112.9428 ± 0.0015			
Albite	8.1167 ± 0.0213	12.7315 ± 0.0413	7.1829 ± 0.025	658.698 ± 2.7542	$94^\circ 42' 59'' \pm 20' 46''$	$116^\circ 45' 21'' \pm 20' 44''$	$91^\circ 42' 20'' \pm 24' 17''$
MCB-16/266.02 (shocked granitoid fragment within melt breccia)							
Quartz	4.9143 ± 0.0001		5.4003 ± 0.0001	112.9431 ± 0.0015			
Microcline	8.6050 ± 0.0417	13.0160 ± 0.0341	7.2243 ± 0.0304	726.1052 ± 3.7314	$91^\circ 25' 18'' \pm 33' 1''$	$116^\circ 8' 16'' \pm 20' 39''$	$88^\circ 28' 29'' \pm 27' 45''$
MCB-16/376.90 (shocked basement granitoid)							
Quartz	4.9116 ± 0.0003		5.4048 ± 0.0006	112.9166 ± 0.0122			
Microcline	8.6697 ± 0.0650	12.9609 ± 0.0082	7.1970 ± 0.0086	726.3650 ± 4.9401	$90^\circ 11' 12'' \pm 8' 19''$	$116^\circ 4' 8'' \pm 11' 11''$	$89^\circ 14' 3'' \pm 16' 33''$
MCB-16/379.11 (shocked basement granitoid)							
Quartz	4.9126 ± 0.00001		5.4022 ± 0.0001	112.9071 ± 0.0017			
Albite	8.1358 ± 0.0037	12.7853 ± 0.0061	7.1504 ± 0.0038	662.7576 ± 0.3329	$94^\circ 33' 52'' \pm 2' 1''$	$116^\circ 37' 45'' \pm 2' 8''$	$87^\circ 40' 7'' \pm 2' 28''$
Microcline	8.6161 ± 0.0359	12.9595 ± 0.0121	7.1996 ± 0.0115	722.9551 ± 2.3235	$90^\circ 41' 48'' \pm 9' 22''$	$115^\circ 47' 49'' \pm 8' 7''$	$87^\circ 17' 45'' \pm 9' 29''$
Standard							
α -Quartz	4.9134		5.4052	113.00	90°	90°	120°
Microcline	8.5784	12.960	7.2112	720.16	$90^\circ 17' 60''$	$116^\circ 2' 60''$	89°
Albite	8.1440	12.787	7.1600	664.40	$94^\circ 15' 57.6''$	$116^\circ 34' 58.8''$	$87^\circ 40' 1.2''$

Figure 8. Sample plots (red) on unit-cell c_0/a_0 vs. Pressure diagram of Angel *et al.* (1997). Angel's samples are represented by dots.

structures, do not retain crystallographic signatures of the high pressure that caused it, due to the preponderance of an amorphous phase of silica during decompression. Huffman *et al.* (1993) and others provided strong evidences of amorphisation of quartz in a solid state. This also explains the anomalously low birefringence of quartz exhibiting PDF-like structures, implying variable degree of decompression-induced amorphisation. Other researches like Somayazulu *et al.* (1994) similarly indicated a precursor phase prior to amorphisation through molecular dynamics. This is supported by NMR spectra studies of shocked quartz which indicates increasing amounts of amorphous phase of silica at pressures >25 GPa.

For albite from shocked granites, a_0 and b_0 are less and c_0 is greater than that of normal high albite (Deer *et al.* 2001) whereas a_0 and b_0 are equal/less than, and c_0 is greater or lesser than that of low albite (Deer *et al.* 2001). The volumes of the unit cell ($658.70, 662.76 \text{ \AA}^3$) are close to $663.1 \text{ \AA}^3$, which is the normal volume at 1 atm and slightly greater than $651.1 \text{ \AA}^3$ which is the normal volume at 11 atm (Hazen and Prewitt 1977). α and β are greater than that of both high and low albite, whereas γ is either greater or lesser than that of high and low albite. For microcline from both breccia and shocked granitoid, a_0 is greater than that of low microcline. The b_0 and c_0 are less than that of low microcline in shocked granite, but greater in

the breccia. The α , β , and γ are either less or more than that of low microcline for all the samples.

5. Discussion

The combined approach of optical microscopy, Micro Raman spectroscopy and XRD technique helps to understand signatures of shock, etched on the rock forming minerals from melt breccia and basement granite of Mohar structure. The studies reveal optical property aberrations of common rock forming minerals, *viz.*, planar deformation, lowered birefringence and mosaics in quartz, toasting and ladder texture in alkali feldspar along with near-isotropism in bytownite, generally coinciding with some degree of structural/crystallographic deviations, as reflected by their Raman spectra and XRD data. Recent micro-Raman characterization of feldspar from this area (Roy *et al.* 2017) also clearly brings out the high degree of irregularity, implying structural damage in grains of PDF quartz and feldspars. In the present study, it is observed from the Raman spectral pattern that, multiplicity of peak groups, peak positions, and peak widths of α quartz and feldspars, vary subtly from their standard spectra. Also additional peaks are observed, *viz.*, for the studied α -quartz marked by multiple PDF-like structures, an extra peak is observed at 1300 cm^{-1} and for toasted orthoclase, small additional peaks are observed around 1300 and 1500 cm^{-1} . For the nearly isotropic bytownite in the shocked mafic clast, the notable aberration includes peak broadening around Raman shift of 700 cm^{-1} and development of a peak at 1300 cm^{-1} . The partial isotropism of bytownite may be suggestive of a non-uniform transformation to glass-like material. Unlike maskelynite (glassy plagioclase), a prominent band broadening and a relative shift of the Raman band from 570 to 600 cm^{-1} is missing in this case. The XRD data indicates modifications in the unit cell parameter of quartz, alkali feldspar and plagioclase with decrease in cell volume. The inter-tetrahedral angle and c_0/a_0 of quartz suggest that the silica tetrahedral structure is not regular and that the inter-tetrahedral angle is in the range of 120° – 144° implying bending of the Si-O-Si angle due to compression and initiation of severe distortion and amorphisation. When plotted in c_0/a_0 vs. P diagram (Angel *et al.* 1997), the four sample points do not signify significant pressure rise, but the optical presence of PDF-like

Figure 9. Si–O–Si angle *vs.* pressure diagram (Hazen *et al.* 1989). Dhala (Mohar) samples are represented by triangles.

structures in these quartz grains sets the pressure range to 8–25 GPa (French 1998). This apparent paradox may be due to the fact that the grains analyzed are possibly intermediate between perfectly crystalline and amorphous stage, occurring perhaps as a precursor prior to total amorphisation. Decompression during shock recovery may also be a cause for this observation. It is also possible that post-shock thermal effect might have caused annealing of shock damage, leaving planar microstructures unaffected (Grieve *et al.* 1996). Using Si–O–Si angle *vs.* pressure diagram (figure 9), the samples from Dhala (Mohar) structure would fall along the line obtained by Hazen *et al.* (1989), suggesting a pressure maxima of about 12 GPa.

Parisite, a calcium, light rare earth element fluorocarbonate, is a rare mineral and is reported from type geological setting of folded carbonaceous shale or in calcite/ankerite veins in hydrothermal deposits, where it is associated with carbonate (www.mindat.org; Gysi and William-Jones 2015). It is rarely reported from granitoids, although bastnaesite, a light rare earth element fluorocarbonate is reported from granitoid rocks. In the studied sample, it occurs as a rare accessory mineral, and is marked by striated nature, high relief, uniaxial positive nature and high birefringence and without any association of carbonate mineral. Parisite rarely occurs as single crystals and most specimens are ‘polycrystals’, syntaxial intergrowths of two species (Donnay and Donnay 1953). Micro Raman data brings out the fact that the crystals under study, although striated, have uniform composition and does not suggest intergrowth of closely related species. This data also shows deviation from the standard data, in having a sharp drop of

Raman shift from 300 to 400 cm^{-1} and absence of a gentle peak at 400 cm^{-1} as observed in the standard Raman spectral pattern. An additional small peak is observed in the sample around 670 cm^{-1} . Considering all these, it appears that the parisite crystals within the basement granite, as confirmed by micro-Raman spectral pattern, suggest lattice aberration due to shock damage. Detailed characterisation of parisite by other techniques remain within the scope of future studies.

Thus, this preliminary finding brings to light the occurrence of the rare mineral, parisite, in the basement granite of Mohar and also qualitatively brings out the anomalous nature of quartz, alkali feldspar and bytownite in shocked basement granite and melt breccia, with respect to their optical, structural and crystallographic properties. The anomalous nature may be attributed to the various shock transformation in an established impact environment.

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