Introduction: We discuss an effect of shock-metamorphism on quartz from impact craters by means of Raman spectroscopy. We would like to demonstrate that Raman spectroscopy is a potential technique, which enables easily characterization of the shock-induced planar microstructures in minerals from different impact environments such as impactites, meteorites and shock recovery experiments.

Samples and Experimental Procedure: Quartz samples used for this study were shocked during the hypervelocity impact events at various shock stages from the terrestrial impact craters including Ries Crater (Germany) and Barringer Meteor Crater (Arizona, the U.S.). They were prepared as polished thin sections using nonluminescent epoxy resin and coated with 20 nm thickness carbon. The planar microstructures (PDFs: Planar Deformation Features and PF: planar fractures) were observed in several shocked quartz grains under a petrographic microscope.

Raman spectra were obtained using a Thermo Nicolet Almega confocal micro-Raman spectrometer with a 20 mW at 532 nm with Nd:YAG laser excitation system and a cooled CCD-detector at 223K. The spectral measurements were carried out at 1 µm intervals over a sectional area of 30 µm square with a 1 sec exposure time. 3D spectral images can be pictured automatically with specialized software of the Almega system and a cooled CCD-detector at 223K. The spectral measurements were carried out at 1 µm intervals over a sectional area of 30 µm square with a 1 sec exposure time. 3D spectral images can be pictured automatically with specialized software of the Almega system.

Principles of Raman Spectroscopy: According to Roberts and Beattie [1], when a monochromatic beam of light illuminates a medium (e.g., gas, liquid or solid), most of the light will traverse the sample without undergoing any change. Approximately 10^5 of the incident intensity is scattered with the same frequency as that of the incident light source (elastic or Rayleigh scattering). Raman scattering (“Raman effect”) occurs when, in addition to the Rayleigh scattering, about 10^-6 of the intensity of the incident light is scattered at new frequencies above and below the incident frequency. A Raman-active vibration can be expected if the polarizability in a molecule is changed during the normal vibration [1]. The frequencies of vibrations depend on the vibrating masses and the forces between them, including the anharmonic nature of interatomic and inter- and intramolecular interactions. If a phase transition occurs, the Raman selection rules, which ultimately depend on crystal and molecular symmetries, will also change (as well as forces), and new spectral features, characteristic for the new structure, will appear [2]. Thus, this method is not only of great help in elucidating crystal structures [3], but can also be used as a method of qualitative analysis (finger-print), e.g., in determining the presence of specific phases in small thin section areas without destroying them.

Results: Raman spectra of shocked quartz from Ries Crater exhibit a pronounced peak at around 459 cm^-1, which can be assigned to Si-O-Si stretching vibration, whereas typical low-quartz has a sharp and intense peak at 464 cm^-1. This frequency shift might be related to a distortion of structural configuration caused by shock-metamorphism. 3D Raman imaging analysis using this Raman peak reveals a stripe pattern suggesting lamination layer comprised of high and low crystalline parts. This 3D Raman image corresponds to the optical image of PDFs.

Discussion: McMillan [4] noted that the bands in the 1200-800 cm^-1 region can be assigned to silicon-oxygen stretching vibrations of tetrahedral silicate units. The weak high-frequency bands of silica glass have been assigned to antisymmetric stretching vibrations of silicate tetrahedra within a fully polymerized tetrahedral silicate network. The strong bands in a glass at 1100-1050 cm^-1, 1000-950 cm^-1, 900 cm^-1, and 850 cm^-1 have been attributed to symmetric stretching vibrations with, respectively, one (=SiO), two (=SiO2), three (-SiO3), and four (SiO4) non-bridging oxygen atoms. The bands in the 700-400 cm^-1 might be associated with the presence of inter-tetrahedral Si-O-Si linkages [4].

Recently, Raman spectra of quartz have been described by e.g., [5]. They found changes in frequency and line-width of the 206 and 464 cm^-1, Raman modes of quartz, which were determined over temperatures from 23 to 800°C and simultaneously at pressures between 0.1 MPa and 2.1 GPa, using a hydrothermal diamond-anvil cell (HDAC). The positions and widths of peaks in the Raman spectra of our measurements are in good agreement with these previous studies. Raman spectra of the coesite high-pressure polymorph of quartz have been reported by Boyer et al. [6], Lou涅jeva et al. [7], and Ostroumov et al. [8]. Boyer et al. [5] found that the strongest coesite line is at 521 cm^-1, with other characteristic lines at 117, 177, and 271 cm^-1. On the other hand, Serghioti et
in laser-heated diamond cell experiments, found that coesite exhibits three relatively strong Raman bands at 489, 552, and 790 cm$^{-1}$ and stishovite shows a strong peak at 790 cm$^{-1}$. These authors concluded that stishovite was converted to coesite at 10 GPa and 2330 °C. We notice that our Raman data are good agreement with the above-mentioned, previous results on the shocked quartz samples.

**Conclusion:** The study of Raman properties of shock-deformed minerals (e.g., quartz) has the potential to provide a tool that can be used in shock barometry, to supplement the methods available so far (mainly optical microscopy; also birefringence and density measurements of shocked quartz are rarely done). Micro-Raman spectroscopy is by now a fairly routine technique that is not too complicated in its use. The identification of a Raman spectroscopic method that would allow to a) identify shocked minerals and their shock-induced microdeformations, and b) give information on the shock pressure would be useful for the identification and study of impact environments such as meteorites, impact-derived glasses (e.g., impact glasses, tektites, etc.), and impactites.

**Acknowledgement.** The authors express grateful thanks for G. Pösges and Th. Kenkmann for the reference samples from the Ries impact structure (Germany) and A. Osada for Raman spectroscopy in Himeji Analysis and Evaluation Center (Japan). This study has been partly supported by Arkansas Center of Space and Planetary Sciences.