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Imaging and visualising nanometre scale surface geometry of a crystalline mineral (SiO_2) in monochromatic spectra

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Abstract : Digital microphotography and image analysis is considered as an important tool in sedimentology and mineralogy for the assessment of physical characteristics at micro and nano level. In this paper the present authors attempted to apply digital imaging technique to visualise the surface geometry of Quartz at nanometre scale. For that purpose a quartz specimen was picked up from microphotography of a thick section of sediment layer and 1µm X 1 µm base image was prepared for digital operation with sophisticated software. Reflectance capacity of the particle has been considered to measure the surface condition. An automated contour plotting was done from the base image. Surface condition was also analysed by reflective radiance measurement. Four images based on greyscale, black body law, pseudo colour composition and landscape were prepared for detailed assessment of quartz nanomorphology. A 3D image was also consulted for understanding the geometry of the surface of quartz.

Keywords: Quartz, Nanoscale, Imaging, Reflectance, Monochromatic, Surface geometry

INTRODUCTION

Silicon dioxide (SiO_2) or commonly known as quartz is the most common precious mineral in the Earth. From physical point of view quartz can be easily recognised by its hexagonal crystallised form and high reflective characters. This mineral is formed by the union of two different compositions of different states like silicon and oxygen. The first one is a substance analogous to carbon and the second one is a gas, principal constituents of atmospheric air. It is simply a matter of the temperature and pressure especially at the time of crystallization that determines which forms silicon dioxide will organise into. Mechanical strength of quartz falls in the 7th category in moho scale of hardness. Therefore it is enable to resist itself from the outer mechanical influence of stronger body. Some early works by Rice (1969), Feigl and Anderson (1970), Sprunt (1981), Bohlen and Boettcher (1982), Richet*et al.* (1982), Serebrennikov *et al*. (1982) presented the physical characteristics of Quartz. With the recent development of scientific tools many advanced researches are conducted to understand the physical natures of quartz. Agrosì *et al.* (1992), Rink *et al.* (1993), Onasch and Vennemann (1995), Stevens Kalceff and Phillips (1995), Carpenter *et al.* (1998a), Götze *et al.* (2001), Botis *et al.* (2005) and Götze *et al.* (2005) focused on different physical characteristics of quartz and its importance as a natural compound. Considering the physical importance of quartz in material and earth sciences we decided to perform an experiment on imaging for visualising nanomorphological characteristics or surface geometry this mineral by digital imaging. The basic objective of this study is viewing the nanomorphology of a very smooth object, surface variation of which cannot be explored even at micro level viewing.

METHODOLOGY

Background of the study: Since this study concentrate on experiment of imaging under reflective light and visualising the surface condition based on reflected radiation, an attempt was made to integrate micro imaging and nanoscale visualising. Some of the previous works on micrography and digital imaging like Bale and Schmidt (1984), Katz and Thompson (1985), Wong *et al* (1986), Jacquin and Adler (1987), Hansen and Skjeltrop (1988), van der Meer (1987, 1993 and 1996), van der Meer and Laban (1990), and Menzies and Maltman (1992) were consulted before the adaptation of methodology. Bryant and Davidson (1996) and Cooper (1998) applied digital image analysis in sediment studies which were also consulted. Vernon (2004), in his recently published book, presented a general outline on practical approach to igneous, sedimentary and metamorphic rock microstructure analysis. The basic concepts of all the above works were followed in the present. Keeping in mind that recent development of nano-science opens a new dimension in sedimentology and mineralogy (Frazer *et al.*, 2004), the present authors use the reference of some very recent works done by Udubasa *et al.* (2007) and Jiang *et al.* (2008).

For the present experiment a thick section was prepared from the sediment sample which was collected during field from 0.36m depth of Rudrasagar lake area of Tripura. Optical microscope and high resolution digital camera (8.5 megapixel) was used for microphotography. A quartz specimen was picked up from the digital colour micro image. In the micro level optical range the selected sample was represented by very smooth and flat yellowish surface which was produced by high level and equal reflection. Some variations of reflectance were observed by pixel level stretching (enhancement) of the image, but they were not enough for in-depth analysis.

Monochromatic imaging: For nanometre analysis typical nanotech software (WSxM4.0 software) was selected which can even read small variations of reflected radiations. From the microphotograph a 1µm X 1µm area was taken for processing final monochromatic data. The raw image was prepared on the basis of two parameters namely, wave length of light and bidirectional reflection distribution function (BRDF). Thus the radiometry of the base image stands on the following two very commonly used algorithms:

$$L = [L_{\lambda_1} \ldots L_{\lambda_k}]^\top \quad \text{(1)}$$

Where,

? = wavelength of light and L = radiance

and

$$f_r(\mathbf{x}, \omega_i \to \omega_o) = \frac{L(\mathbf{x} \to \omega_o)}{L_i(\mathbf{x} \leftarrow \omega_i)\, \mathrm{d}_\perp \omega_i} \quad \text{(2)}$$

Where, *fr*= bidirectional reflection distribution function for a surface point, x= ratio of the reflected radiance, *Li* = incoming radiance, *L*= outgoing radiance, *i*= differential irradiance for an incident direction.

Smooth filter was used on raw data for image processing before various operations (Fig.1). The surface of the selected sample was tested by vector based contour plotting and drawing serial profiles. Visualising the quartz surface is a multi-processing soft computing approach which consists of four different operations for understanding the capacity of information at nanoscale. Different patterns colour sets, produced by pixel by pixel measurement, are used for surface analysis and their significances are of studied (Fig.2).

RESULTS AND DISCUSSION

Contour plotting: The contour plotting is an automated operation for vector based visualization of the processed filtered data (image). In this operation the range of elevation 519.2592 nm is measured within 0.00 to 1.05 µm visibility levels which are expressed from white to black in yellow bin). In the contour plotting white is considered as maximum height 253. 3106 nm and black is represented by minimum height -265.9486 nm. The intermediate heights are expressed by light yellow to dark brown. The middle point is measured as -5.6810 nm.

The contour distribution shows a tendency of parallel contour distribution with a gradual alteration of high to low values. Drawn cross profiles AB, CD, EF and GH show two prominent parallel peaks and two adjoining parallel troughs. The cross sections along peaks and troughs show that the surface conditions are very uneven. The AB profile has drawn on the trough which shows a range of elevation varies around 295 nm. Profile GH is another cross section which shows similar kind of elevation range in trough. Two profiles CD and EF on the peaks are drawn which are the example of the comparatively less elevation variations along the section lines. Profile CD shows lowest elevation range of 80 nm and EF shows range of 200nm.

Soft computing and visualising the surface conditions under reflective light: In this study four images were prepared (Fig.3) by soft computing namely (i) based on greyscale, (ii) based on black body law, (iii) based on pseudo colour (iv) based on grouping of contours (landscape). The greyscale image is represented the result of measuring the intensity of light at each pixel in a single band within 8 bit radiometry. Since the range of 1.05 µm is represented within greyscale of 8 bit radiometry from white (strongest) to black (weakest) the rise and fall of the surface of the sample is clearly visible. "Black body" is considered as an object (here quartz sample) which absorbed all electrometric radiation. In this operation the optical range varies from white, off-white, light yellow, yellow, deep yellow, radish yellow, deep red, reddish brown, dark brown up to black. A greater visibility level of surface variations than the 8 bit radiometry has been produced within the range of black body colour sets.

Pseudo image is a multicolour presentation which is originally prepared from mono-spectral image. It is a result of pixel by pixel measurement in which fractional variations of changes can be detected by variations of different colours. The negative point (here-5.6810 nm) is represented by blue. It is sure that pseudo-colouring does not increase the information contents of the original image; still it can provide more details of surface condition as increase visibility range between successive grey levels. Different colours recognise even the fractions of measured nano-relief values. Unlike the above discussed three reflectivity based operations, landscape operation is based on the grouping of elevations according to contour distribution which is originally produced from the processed monochromatic base image. The colour sets of this figure are the indicator of elevation group or elevation class.

The interpretations of above visibility testing by digital imaging are also supported by the 3D view prepared (Fig.5) from the samples. Morphological view of the sample 3D clearly shows that there are two fall and three rise comprising the nanoarchitecture of the sample. For convenience we have plotted a longitudinal profile across the sample to examine the elevation range of surface condition within 1 µm vertical extension.

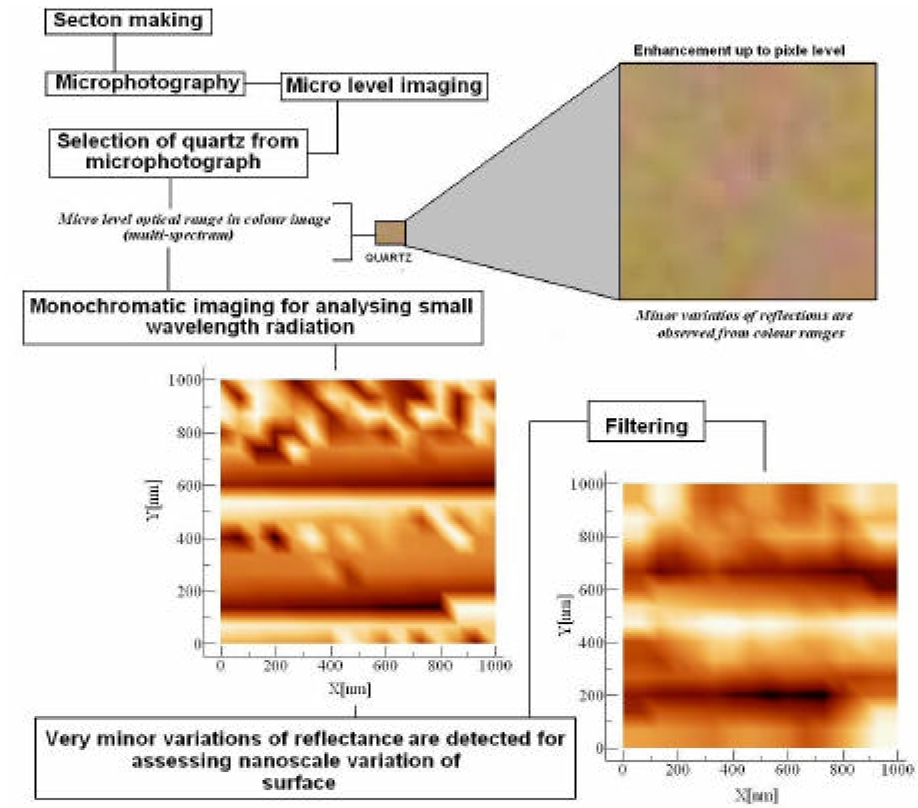


Fig.1. Flow chart of methodology of imaging and image processing.

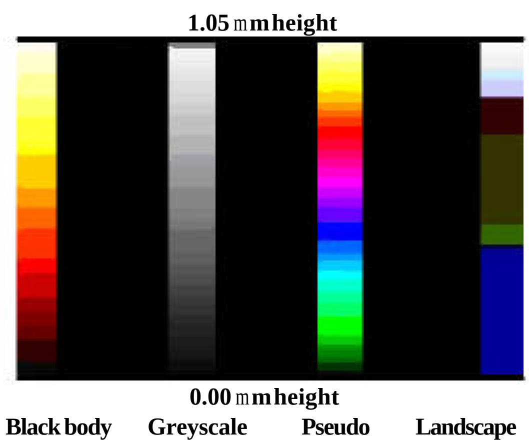


Fig.2. Colour sets produced by image based measurements.

Conclusion

The physical base monochromatic imaging is standing on the source of light and reflectivity capacity of any object which is expressed within the range of black (low) to white (high) in specific spectra. When the object is under reflective light visibility level of the image is dependent on reflected radiations. Through the present study it has been observed that monospectral imaging is very suitable to assess the morphology even at nanometre scale. Rise and fall of heights at nanometre are visible by the changing of radiations. In this experiment nanomorphology is analysed by 3D and some profile drawing which are actually based on reflected radiation values. A logical roughness analysis has also been done from monospectral image which shows the efficiency of perfect computation within monochromatic parameters for understanding the spatial characters of any smallest object.

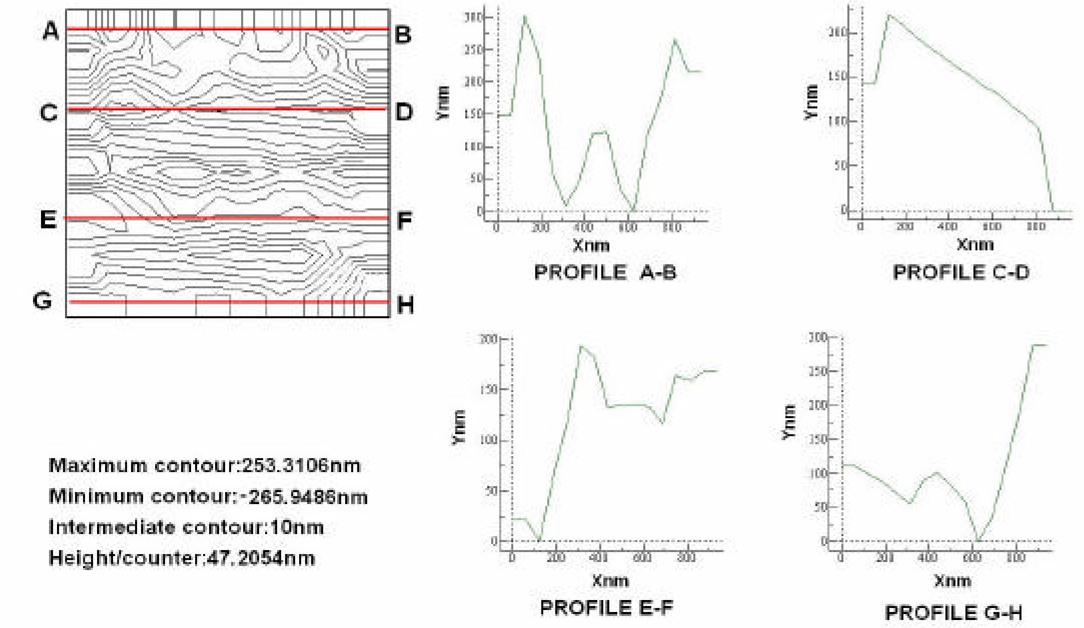
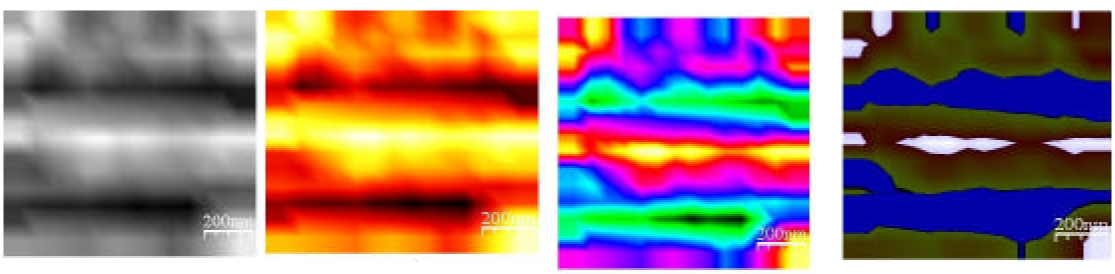


Fig.3. Contour plotting, automated vector based operation.



a **b** **c** **d**

Fig.4. Visualisation of soft computations (a) greyscale, (b) black body, (c) pseudo and (d) landscape .

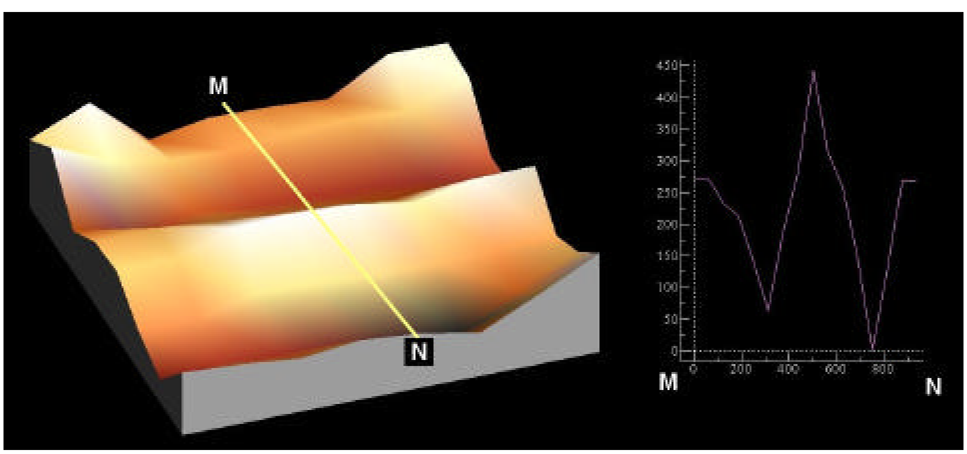


Fig.5. 3D viewing of quartz sample.

REFERENCES

Agrosì, G., Lattanzi, P., Ruggieri, G., and Scandale, E.(1992). Growth history of a quartz crystal from growth marks and fluid inclusions data. *Neues Jahrbuch für Mineralogie, Monatshefte,* 7:289-294.

Bale, H.D and Schmidt, P.W. (1984).Small-angle X-ray scattering investigation of submicroscopic porosity with fractal properties. *Physical Review Letters*, 53: 596-599

Bohlen, S.R. and Boettcher, A.L.(1982). The quartz-coesite transformation: a precise determination and the effects of other components. *Journal of Geophysical Research*: 87(B8):7073-7078.

Botis, S., Nokhrin, S.M., Pan, Y., Xu, Y., and Bonli, T. (2005) Natural radiation-induced damage in quartz. I. Correlations between cathodoluminence colors and paramagnetic defects. *Canadian Mineralogist*, 43:1565-1580.

Bryant, R.G. and Davidson, D.A. (1996). The use of image analysis in the micromorphological study of old cultivated soils: an evaluation based on a case study from the island of Papa Stour, Shetland; *Journal of Archaeological Science,* 23:811-822

Carpenter, M.A., Salje, E.K.H., Gaeme-Barber, A., Wruck, B., Dove, M.T., and Knight, K.S. (1998a). Calibration of excess thermodynamic properties and elastic constant variations associated with the a - ß phase transition in quartz. *American Mineralogist*, 83:2-22.

Cooper, M.C. (1998). The use of digital image analysis in the study of laminated sediments. *Journal of Paleolimnology,* 19 : 33-40

Frazer, B. H., Girasole, M.L., Wiese, M., Franz T. and De Stasio G.(2004). Spectromicroscope for the PHotoelectron Imaging of Nanostructures with X- rays (SPHINX): performance in biology, medicine and geology, *Ultramicroscopy,* 99 : 87-94.

Feigl, F.J. and Anderson, J.H. (1970). Defects in crystalline quartz: electron paramagnetic resonance of E' vacancy centers associated with germanium impurities. *Journal of Physics and Chemistry of Solids,* 31:575-596.

Götze, J., Plötze, M., Fuchs, H., and Habermann, D. (2001). Origin, spectral characteristics and practical applications of the cathodoluminescence (CL) of quartz - a review. *Mineralogy and Petrology,* 71:225-250.

Götze, J., Plötze, M., and Trautmann, T. (2005). Structure and luminescence characteristics of quartz from pegmatites. American *Mineralogist,* 90:13-21.

Jiang, H., Ramunno-Johnson, D., Song, C., Amirbekian, B., Kohmura, Y., Nishino, Y. Takahashi, Y., Ishikawa, T. and Miao J. (2008). Nanoscale Imaging of Mineral Crystals inside Biological Composite Materials Using X-Ray Diffraction Microscopy; *Physical Review Letters,* DOI: 10.1103/ PhysRevLett.100.038103,

Hansen, J.P. and Skjeltrop, A.P. (1988). Fractal pore space and rock permeability implications; *Physical Review,* B, 38, 2635-2638.

Katz, A.J. and Thompson, A.H. (1985). Fractal sandstone pores: implications for conductivity and pore formation; *Physical Review Letters*, 54, Pp-1325-1328.

Jacquin C.G and Adler, P.M. (1987). Geometry of porous geological structures; Transport in Porous Media 2, 571-596.

Menzies, J., and Maltman, A. J., (1992). Microstructures in diamictons–Evidence of subglacial bed conditions. *Geomorphology*, 6 : 27–40.

Onasch, C.M. and Vennemann, T.W. (1995). Disequilibrium partitioning of oxygen isotopes associated with sector zoning in quartz. *Geology,* 23: 1103-1106.

Rice, S.J. (1969). Quartz family minerals. California Division of Mines and Geology. *Mineral Information Service*, 22: 35-38.

Richet, P., Bottinga, Y., Deniélou, L., Petitet, J.P., and Téqui, C. (1982). Thermodynamic properties of quartz, cristobalite, and amorphous SiO2: drop calorimetry measurements between 1000 and 1800 K and a review from 0 to 2000 K. *Geochimica et Cosmochmica Acta* , 46:2639-2658.

Rink, W.J., Rendell, H., Marseglia, E.A., Luff, B.J., and Townsend, P.D. (1993). Thermoluminescence spectra of igneous quartz and hydrothermal vein quartz. *Physics and Chemistry of Mineral,*:20:353-361.

Serebrennikov, A.J., Valter, A.A., Mashkovtsev, R.I., and Scherbakova, M.Ya. (1982). The investigation of defects in shock-metamorphosed quartz. *Physics and Chemistry of Minerals,* 8:155-157.

Sprunt, E.S. (1981). Causes of quartz cathodoluminescence colours. *Scan. Elec. Micros*., 525-535.

Stevens Kalceff, M.A. and Phillips, M.R. (1995) Cathodoluminescence microcharacterization of the defect structure of quartz. *Physics Review,* B 52: 3122-3134.

Udubasa, G.,Constantinescu, S., Popescu-Pogrion, N., Hirtopanu1, P. and Udubasa, S.S. (2007). Nano-minerals identification by different physical techniques. *Romanian Reports in Physics,* 59: (3) 819–824.

van der Meer, J. J. M. (1987). Micromorphology of glacial sediments as a tool in distinguishing genetic varieties of till; Geological Survey of Finland, Special Paper 3, Pp- 77–89.

van der Meer, J. J. M. and Laban, C. (1990). Micromorphology of some North Sea till samples, a pilot study; *Journal of Quaternary Science*, 5 : 95–101.

van der Meer, J. J. M. (1993). Microscopic evidence of subglacial deformation, *Quaternary Science Reviews,* 12 : 553–587.

van der Meer, J. J. M. (1996). Micromorphology, *in* Menzies; J., ed., Glacial environments, Oxford, Butterworth-Heinmann, 2: Pp. 335–355.

Vernon, R. H. (2004): A Practical Guide to Rock Microstructure, Cambridge University Press, UK.

Wong, P.Z., Howard, J.and Lin J.S. (1986). Surface roughening and the fractal nature of rocks; *Physical Review Letters,* 57 : 637-640.