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Tomography imaging of South African archaeological and heritage stone and pottery objects

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a r t i c l e i n f o

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a b s t r a c t

We demonstrate the use of both neutron- and X-ray imaging in two projects. The first project, using both the methods to view the temper in a ceramic sherd in order to model the effect the chemical composition of the temper has on the bulk chemical composition of the sherd showed that X-ray imaging is superior to neutron imaging for a ceramic. The second project, to establish whether apparent incised lines on stone slabs (dated to greater than 180,000 years ago) are natural or artificial, i.e., whether they were deliberately incised or natural, random striations showed conclusively that the incisions are in fact surface manifestations of natural internal fractures in the rock.

1. Introduction

The principle of applying Tomography via the penetrating nature of neutron and X-rays has the advantage of providing a non-destructive visual analysis of the interior of archaeological and cultural heritage artefacts in order to assess structural issues relating to their manufacture or alteration due to use, damage, repair or conservation. This applies specifically to rare or unique and precious items that are not suitable for destructive analysis as demonstrated by Rant et al [1]. The experiments described below provide examples showing the power of the technique to South African archaeologists and other heritage professionals and also complements a previous study on metallic objects [2].

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2. Scanning parameters

Thermal neutrons, emerging from beam port-2 at the SAFARI-1 nuclear research reactor penetrate through the sample, casting a shadow image (radiograph) of the sample containing information of the internals onto a detector. The detector is a scintillator screen changing the neutron image into a 2D visible image–detected by a CCD camera (1024 1024 pixel array), which captures a visual image from the scintillator and displays it on a computer screen (see full description of the facility elsewhere) [3].

Many radiographs of the object at different angles of rotation are captured. Through computer algorithms and processing (Octopus software) a 3D virtual image is generated and visualised through VG Studio specialized computer software [4,5].

2.1. For the samples

The samples were rotated through 360l angle of rotation and through 375 numbers of projections to produce high quality tomograms. The subsequent voxel resolution of 0.0977 mm

0.0977 mm 0.0977 mm has been achieved, with the samples placed 80 mm from the scintillator screens–Lithium Zinc sulphide scintillator screen for the thermal neutrons and Gadolinium Oxy sulphide screen for the X-ray detection.

2.2. Volumes

The virtual 3-dimensional image being generated is built of voxels (3D elements) with dimensions relating to the spatial resolution of the object as well as a grey scale value (265 grey scales for an 8 bit image and 65,536 grey scales for 16 bit image) that represents the degree of radiation absorption or scattering of that specific picture element. For a certain material, as part of a composition, this value is unique within the sample.

2.3. Total volume of ceramic sherd sample

A calculation of all the voxels representing the total sample represents 100% volume.

2.4. Volume of inclusions

The inclusions in a sample normally have a different X-ray or neutron absorption/scattering to the matrix material. Through selection of the specific voxels (segmentation) representing only the inclusion, the number of voxels is known and thus the percentage material of that kind within the total sample.

3. Analysis of a tempered ceramic sherd

Provenancing ceramics is carried out in order to establish regional trade and exchange patterns [6]. This is done by linking the chemical composition of a ceramic to a known clay or a distinctive geological source. South African pre-colonial ceramics are regularly tempered, often heavily, with quartz or other grit, crushed ceramics, marine shell and even bone and charcoal. If the chemical composition of the temper is significantly different from that of the original clay, it will affect the chemical signature of the clay, particularly, if a bulk analysis of the sherd is carried out. This makes provenancing the ceramic difficult. It is also a matter of interest to determine whether different potters, using the same clay, had different methods of clay preparation, particularly the way they prepared the raw clay. In order to non-destructively measure the percentage of temper relative to that of the clay both neutrons and X-rays were used in order to compare their effectiveness. As the inclusions in a ceramic normally have different X-ray or neutron absorption/scattering to the matrix material this provides the means for determining its volume. Through selection of the specific voxels (segmentation) representing only the inclusions, the number of voxels is known and thus, the percentage material of that kind within the total sample can be determined. As many sherds, particularly those that may be trade items, are small in size and scarce to unique in number and cannot always be physically sampled for destructive analysis, tomography offers an alternative means of analysis.

3.1. Results

A ceramic sherd, LM229, from the site of Leokwe Hill, Shashe-Limpopo Valley, Limpopo Province was chosen for the analysis [6]. Fig. 1 shows the low contrast tomograph using neutrons. Fig. 2 shows that the X-ray tomography yielded better resolution and contrast between matrix and inclusions, and it was decided to use this for the calculations. The black spots represent voids, the lighter areas represent the inclusions comprising mainly quartz and other types of grit, whilst the grey/dark grey represents the clay matrix from which the former two are clearly differentiated. The calculation of the volume of the inclusions relative to the volume of the whole sherd was carried out using ImageJ software. Three random 2D slices yielded inclusion volumes of 12.5%, 15.1% and 10.6% with an average of 12.7%. The total 3D volume of the inclusions for this sherd was 16.2%. Thus, using a single element, Cr, based on an actual result [2] as a simple example, if it is known that the value of the clay matrix is 96 ppm and of the sherd as a whole (clay plus 16.2% temper) is 168 ppm, then one can infer the value of temper to be 414 ppm, as the experimental work has shown that there exists a simple linear relationship between the relative amounts of clay and temper to the bulk or total composition. Thus, the values of the clay and the temper over a range of

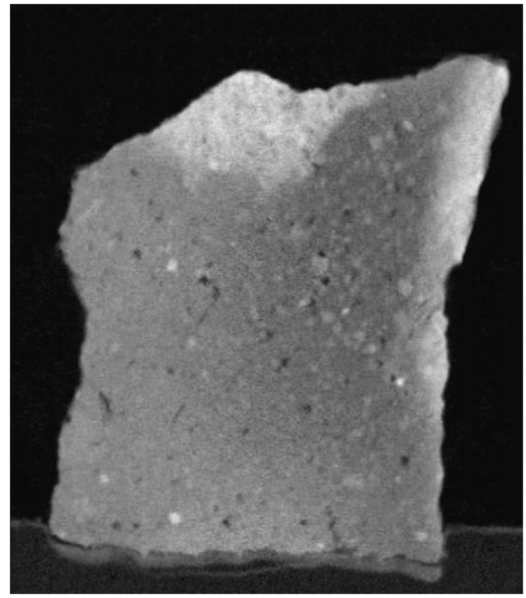

Fig. 1. Neutron tomography of a random slice, through the ceramic sherd, showing a bland, low contrast result.

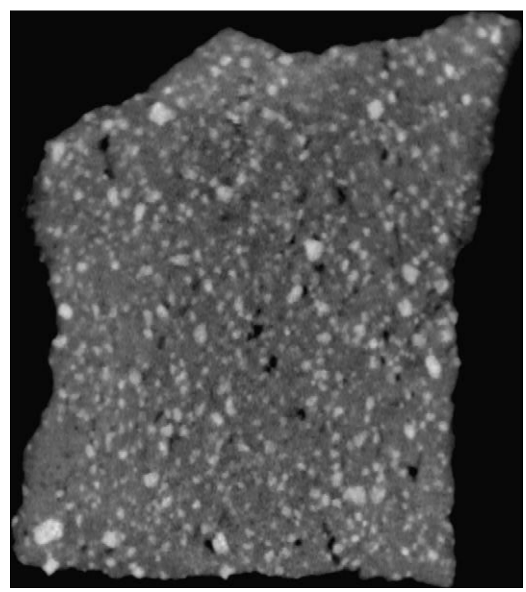

Fig. 2. X-ray tomography of a random slice, through the sherd, showing better resolution and contrast between the matrix and the inclusions.

elements may individually be used to fix a more accurate provenance for a ceramic. A large sample size will also be necessary to attempt to differentiate different potter techniques. Further experimental work to identify actual minerals is also needed.

4. ''Engraved'' rock slab

During the course of archaeological excavations at Wonderwerk Cave, Northern Cape, South Africa, a number of apparently engraved or incised rock slabs were found in levels dating to 180 k years or older [7,8]. These were interpreted to be the evidence for the earliest art objects ever found and preceded the age of previous known objects interpreted as "art" dating back to some 50 k years or more [9]. If true, these would represent the earliest examples of symbolic behaviour long before modern *Homo* dispersed out of Africa. Close inspection of the slabs, however, revealed features that one of us [LJ] interpreted as fissures or cracks, i.e., other natural phenomenon in the rock. It was decided, therefore, that non-destructive tomography would be the ideal means to test this assumption. Accordingly, the most outstanding piece, BB147 (Fig. 3), was chosen for analysis with neutrons. Figs. 4–6 illustrate slices at depths of 2, 6 and 8 mm, all clearly showing the so-called engraved lines to be natural fissures

Fig. 3. Sample BB147. Dimensions are approximately: height 105 mm, width 72 mm and thickness 42 mm. Note the cross hatching giving the impression that it had been decorated.

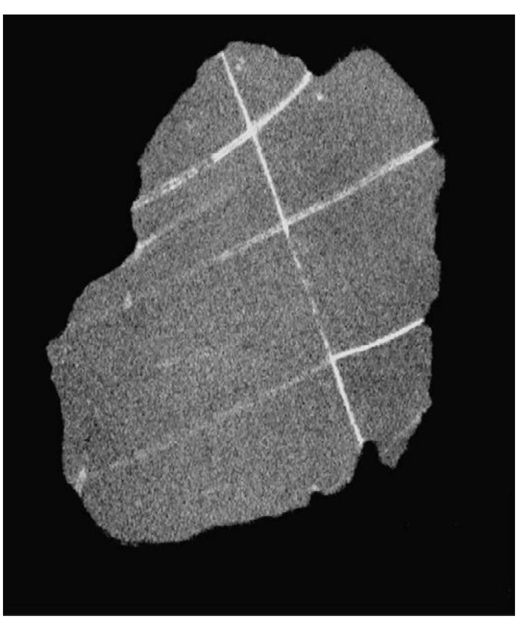

Fig. 4. 2D slice at a depth of 2 mm.

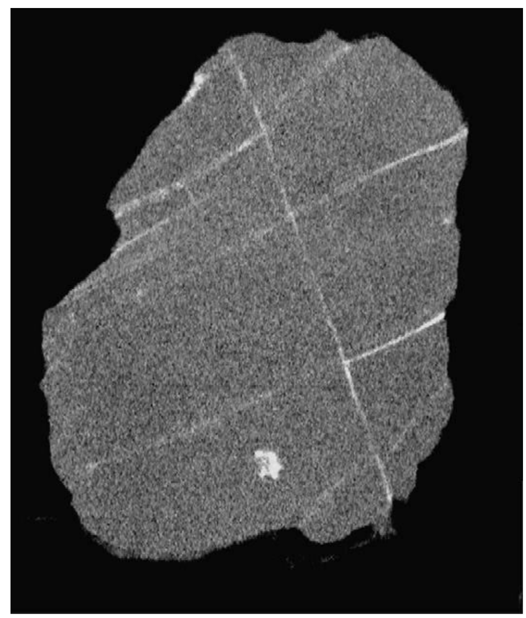

Fig. 5. 2D slice at a depth of 6 mm.

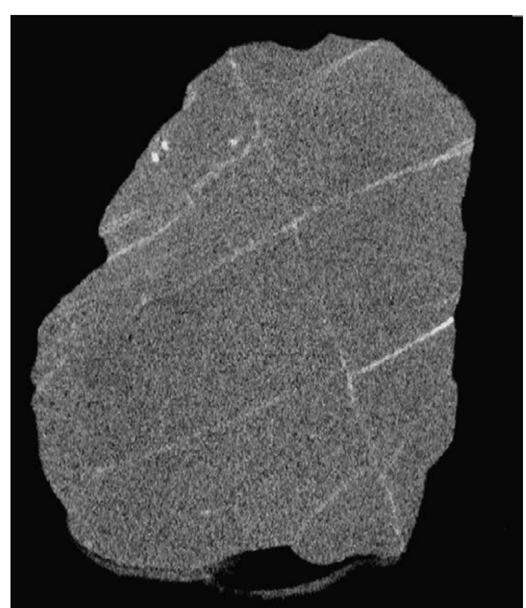

Fig. 6. 2D slice at a depth of 8 mm.

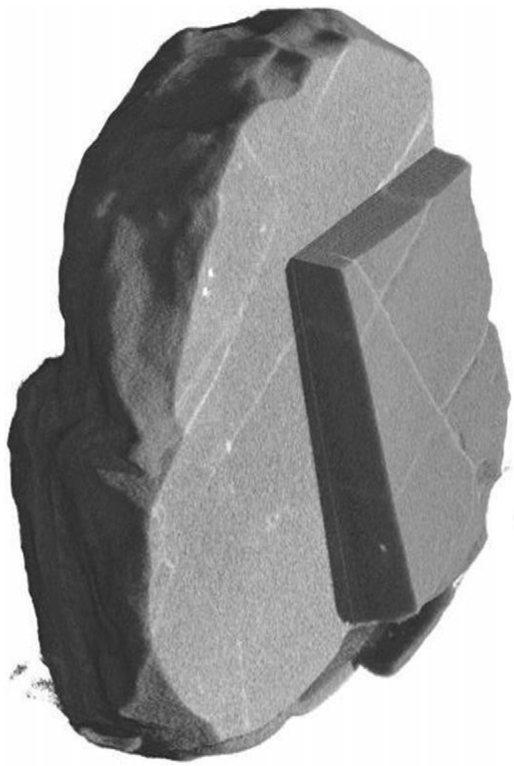

Fig. 7. 3D tomogram showing slices from 2 directions into the sample. Fissures are clearly visible.

extending deep into the rock slab. No Stone Age toolmaker or “artist” could have engraved such lines. Subsequent to their formation the fissures must have been filled with other sediment shown clearly in the tomography (Fig. 7).

5. Conclusions

Tomography has clearly shown its potential as a tool for dealing with problems presented by heritage objects that are too valuable for any kind of destructive testing. In particular, the success in debunking a fanciful notion regarding the early origins of artistic expression and symbolic behaviour should be applied to other controversial examples as and when they are proposed.

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