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Fractal analysis of digital images of flint microwear

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11.1 Introduction

The fractal geometry of Mandelbrot (Mandelbrot 1977) has recently yielded new insight into the study of stochastic processes which possess scale invariance. Fractals are essentially spatial distributions or patterns which possess self-similarity—*i.e.* there is a statistical equivalence between small-scale and large-scale fluctuations in these patterns. The classic example of a fractal is a coastline which appears to have the same degree of random structure when viewed at different space scales.

Interestingly, Mandelbrot and others have observed that many patterns in the natural world appear to be of self-similar fractal form and, furthermore, that eroding processes in nature generate surfaces with fractal properties. Recent work has shown, moreover, that the fractal characteristics of surfaces are closely related to the way in which humans perceive their roughness or texture (Pentland 1985). Fractal analysis has therefore been applied in recent years to the segmentation of digital images of natural out-door scenes and of high resolution remotely-sensed satellite imagery. Topographic surfaces derived from different geological processes can be differentiated in images on the basis of their

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fractal dimensions. Fractal geometry is also now widely-used by the computer graphics community to render natural landscapes in animation applications to achieve high degrees of 'realism'.

To date fractal analysis has not been used in archaeological image analysis, although the authors believe that there are several problems for which this approach could be invaluable. One such problem is the quantitative analysis and interpretation of flint microwear polishes. Over the last four years a study has been undertaken at the Institute of Archaeology to experimentally test the claim that the types of material contacted can be determined from microscope examination of the microwear polish. Quantitative experiments with a digital image processing system at the Institute (Newcomer *et al.* 1986) have so far shown that it is impossible to distinguish between polishes created by different functions on the basis of standard statistical analysis of image texture. This finding is fundamentally at odds with those who claim to be able to subjectively distinguish tool usage on the basis of microscope examination alone.

However, it is now well-known that the perception of image textures by human visual examination is an extremely complex process (Julesz 1981) and there is no guarantee that the methods of image analysis applied to flint tools to date have necessarily found a texture model which is appropriate to the types of surface found on the flint microwear images. The importance of fractal analysis of surface images is that fractal dimension (a statistical measure of image self-similarity) has been found to be very highly correlated to subjective estimates of surface roughness (Pentland 1984).

Since it is now generally accepted (a) that eroding processes create fractal surfaces and (b) that fractal dimensionality is linked to human perception of natural texture, we have recently begun work on the fractal analysis of flint microwear images in the hope that we may be able to resolve the existing controversy. Intuition would suggest that fractal dimension is likely to be a key image property that would vary with different eroding processes and also be linked to the subjective perception of the surface texture or edge shape.

11.2 Experimental method

Our investigation to date has concentrated on finding (i) whether polished and unpolished flint surfaces are fractal in nature and (ii) what fractal dimensions appear to characterise flint surfaces for which fractal behaviour is proved. Fractal dimension is a parameter which expresses the apparent 'roughness' of the texture pattern.

The images for our study were captured in the Microwear Laboratory of the Institute of Archaeology at UCL. They were digitised to 256 grey-levels and each picture contains 256 × 256 pixels. Magnifications of × 100 and × 200 were used for polished and unpolished flints. Initially the images were stored on an IBM-PC-XT. However, because of the intensive nature of the fractal dimension calculations they were transferred to a VaxStation GPX computer in the Department of Computer Science for high speed analysis. Programs were written to extract the necessary spatial statistics to compute the stability of fractal properties over various image space scales and to determine the related fractal dimensions.

11.3 Fractal mathematics

A stochastic function $I(x)$ is fractal if for all x and Δx:

$$Pr\left[|\Delta I_{\Delta x}|\|\Delta x\|^{-H} < y\right] = erf(y) \tag{11.1}$$

where Pr denotes probability, H is the Brown zeroset dimension (see Mandelbrot 1982 for example) and $|\Delta I_{\Delta x}|$ is equivalent to $|I(x+\Delta x) - I(x)|$. This relation implies that $|\Delta I_{\Delta x}|\|\Delta x\|^{-H}$ is normally distributed for all space scales Δx and for all positions x in an image if the surface is fractal. The power law relation between ΔI and Δx should remain constant at all space scales (with a constant H value). Hence we have the following relation for the expectation values of these distributions at different Δx:

$$E(|\Delta I_{\Delta x}|\|\Delta x\|^{-H}) = E(|\Delta I_{\Delta x=1}|) \tag{11.2}$$

By re-arranging this equation and taking logs we have:

$$1nE(|\Delta I_{\Delta x}|) = H1n\|\Delta x\| - 1nE(|\Delta I_{\Delta x=1}|) \tag{11.3}$$

This expresses a linear relationship between the log of the expectation values of intensity change distributions and the log of the image distance. The gradient of this relationship is equal to H the zeroset dimension. A given image can be proved to be fractal if its 'H' value stays constant over a reasonably wide range of space scales (empirically at least a factor of three in space scale from other fractal studies). The fractal dimension D of these image surfaces can also be shown to be equal to 3+H for a 2D image of a 3D surface.

We have therefore investigated the distribution of intensity changes ΔI for different image distances Δx ranging from 1 to 35 pixels. This enables us to directly establish a range over which H is constant and to determine absolute D values using a least squares regression on the graphs of equation 3.

11.4 Results

Fractal dimensions were calculated for a total of seven test flint images. These images included both polished and unpolished surfaces. The polished images represented flints that had been used to work cortex, wood and antler.

Figs. 11.1 and 11.2 show our microscope images for one particular flint which had been used to work antler. Fig. 11.1 shows a region of the flint well away from the contact area; Fig. 11.2 shows a region on the contact edge. It is apparent that the contact area shows an increased abundance of microwear polish (the lighter areas) which have been caused by the eroding/polishing process. We are interested in quantitatively assessing whether these imaged surfaces can be reliably differentiated on the basis of fractal properties.

Figs. 11.3 and 11.4 show the distributions of intensity changes for the same antler-polished flint at space-scales of $\Delta x = 3$ and $\Delta x = 25$ pixels respectively. It is clear that at both scales these distributions are effectively Gaussian. Also, the distribution is wider for the larger space scale indicating a relationship between the expected values of ΔI and scale Δx as would be found for a true fractal.

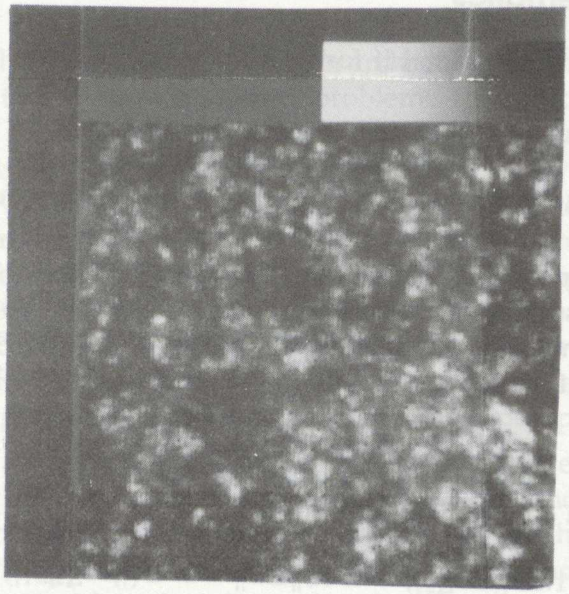

Figure 11.1: Unpolished section of antler-worked flint. [Magnification × 200].

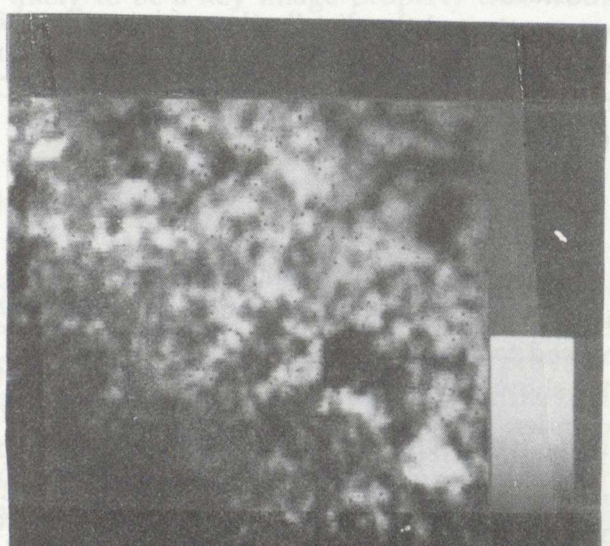

Figure 11.2: Antler-polished flint area. [Magnification × 200].

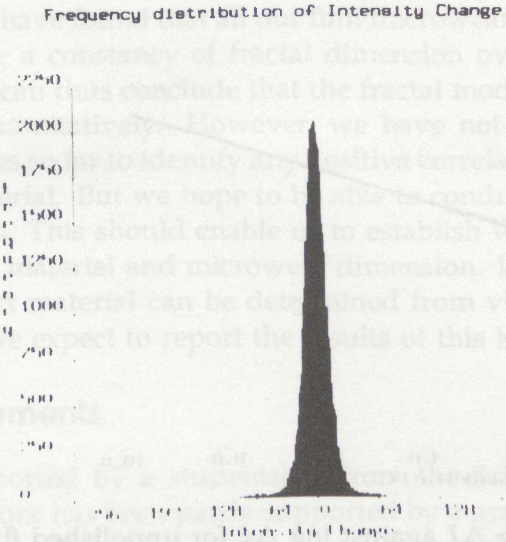

Figure 11.3: Frequency distribution of image intensity changes for Δx = 3. [Antler-polished flint].

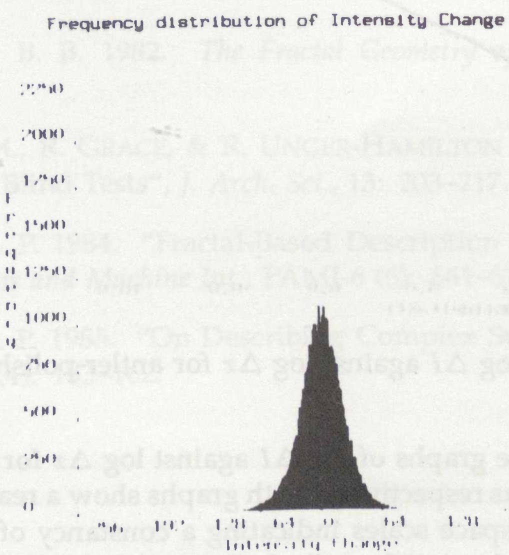

Figure 11.4: Frequency distributions of image intensity changes for Δx = 25. [Antler-polished flint].

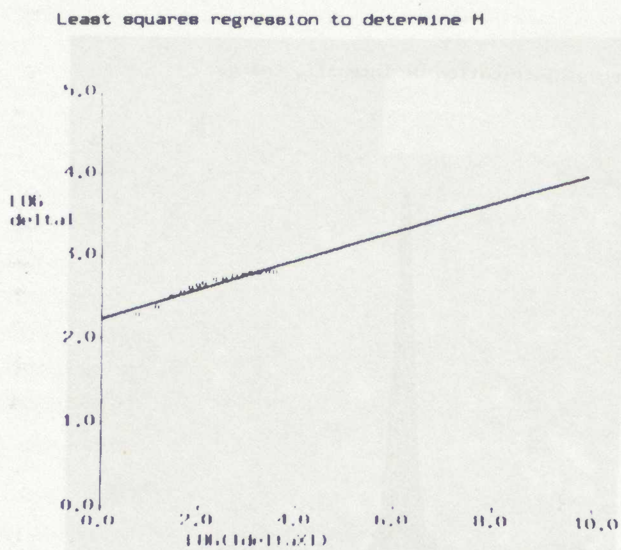

Figure 11.5: Graph of log ΔI against log Δx for unpolished flint area.

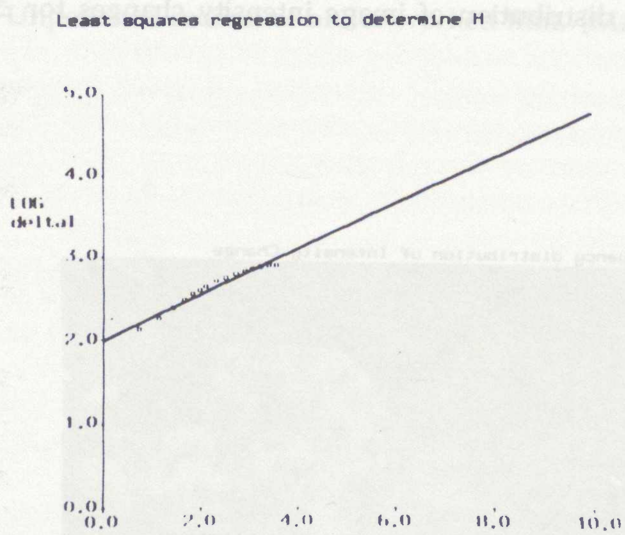

Figure 11.6: Graph of log ΔI against log Δx for antler-polished flint.

Figures 11.5 and 11.5 show the graphs of log ΔI against log Δx for the same flint in its unpolished and polished areas respectively. Both graphs show a reasonably constant gradient over a wide range of space scales indicating a constancy of H. We can thus conclude that the images are behaving fractally both in the unpolished and polished states (although we are reluctant to give fractal dimension figures for our small number of results at this stage).

Overall we can say that all our images were found to be fractal and there appear to be significant differences between the dimensions of the polished and unpolished surfaces for certain types of worked material (especially those contacted by cortex and antler, though less so for wood).

11.5 Conclusions

At this stage we have found that all our flint microwear images are behaving in a fractal manner showing a constancy of fractal dimension over a reasonably wide change in space scale. We can thus conclude that the fractal model is a good one for interpreting these images quantitatively. However, we have not been able to study a sufficient number of images so far to identify any positive correlations between fractal dimensions and contact material. But we hope to be able to conduct tests on larger samples in the next few months. This should enable us to establish whether a quantitative link exists between contact material and microwear dimension. If it does, this would support the view that contact material can be determined from visual examination of microscope images alone. We expect to report the results of this in due course.

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